UNCOVERED FUTURE TREASURE-HUNTING TECH

HOW IT WORKS

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The breakthroughs that will help you live longer

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REVEALED

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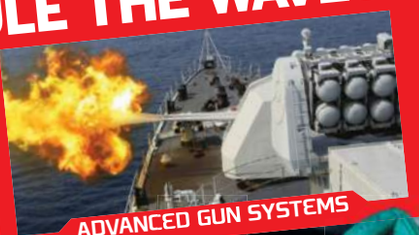
ADVANCED GUN SYSTEMS

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AMAZING GLOW IN THE DARK ANIMALS!

How creatures make their own light in the darkness

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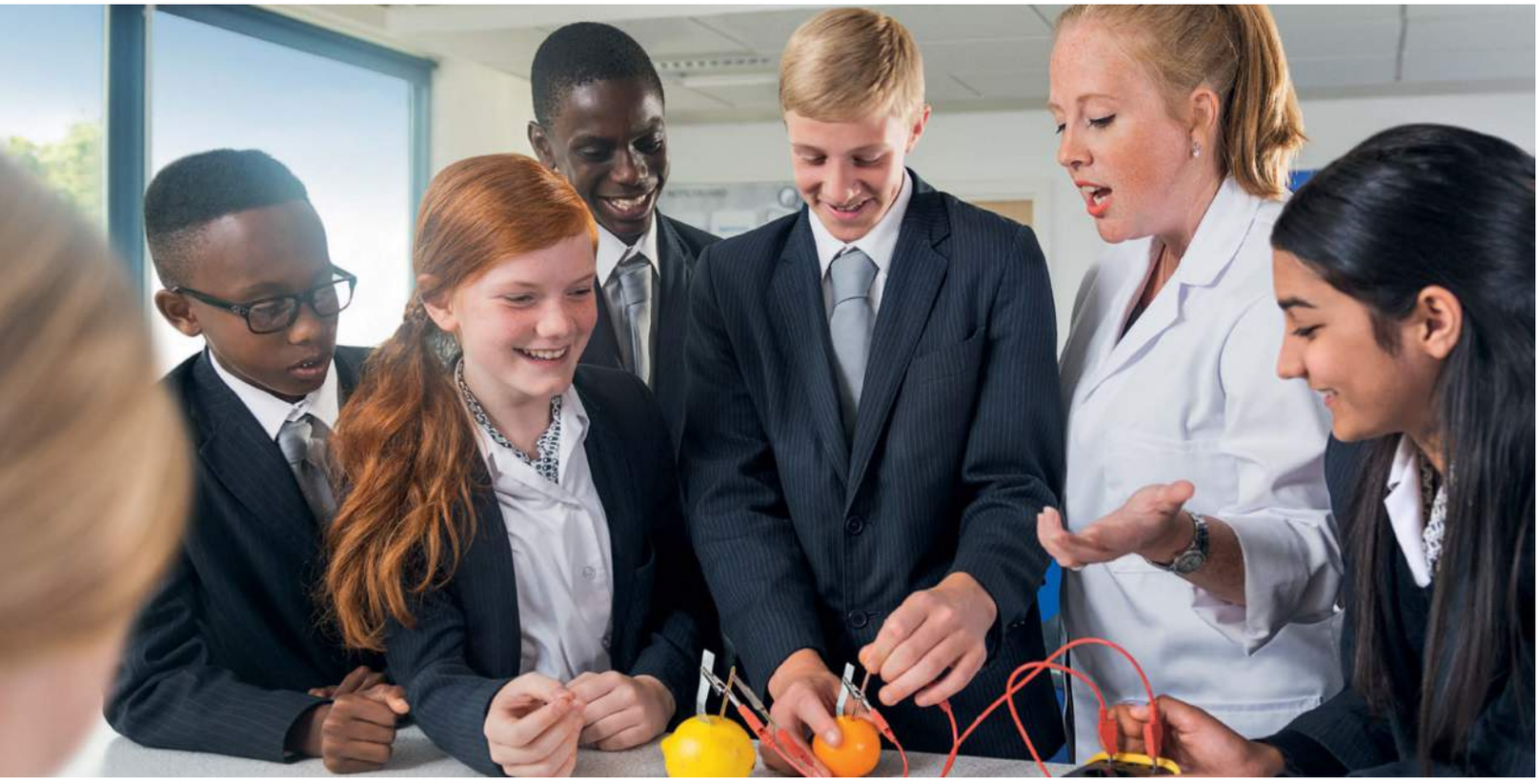
and give students the power to reach their potential.



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ISSUE 80

WELCOME

The magazine that feeds minds!

Page 58
Discover the creatures that can light up the oceans

What an amazing year 2015 shaped up to be! We got our first ever look at Pluto, the Curiosity rover found water on Mars and down here on Earth, scientists uncovered the first new antibiotic in decades! Find out how this will help fight the growing threat of superbugs over on page 26.

It's part of our bumper-sized celebration of discoveries that we've dubbed 'miracle science', because no other words could describe the feats that can be achieved thanks to these revolutionary drugs and techniques. There has never been a more exciting time to be reading a science magazine, or a better time of year!

As the winter nights draw in, you can cosy up with our Victorian Séances Debunked feature (page 68), where we expose the not-so-subtle tricks of 19th century charlatans. Switch on the Christmas lights and then marvel at the way some animals can create their own glow in the darkness (page 58), or watch a re-run of *Indiana Jones* while exploring the real Temple Of Doom (page 44).

Have a wonderful festive season and we'll see you in 2016!

Jodie

Jodie Tyley
Editor

Meet the team...

Andy
Art Editor
This is my last issue before moving over to sister mag **games™**, but what a brilliant one to end on! Hope you enjoy it as much as I did.

Katy
Production Editor
I'd be keen to explore the maze of Tsingy de Bemaraha, although knowing my sense of direction, I'd never make it out again!

Phil
Staff Writer
Unlike modern commercial flights, passengers in the 1950s had ample leg room and good food as standard!

Jackie
Research Editor
I believe in miracles... the ones in our feature anway! I'd choose stem cells over the old 'water into wine' trick any day.

Briony
Assistant Designer
At last! A scientific explanation for one of my biggest daily struggles: 'hanger'. Now I know why I crave those treat-sprinkled cronuts.

Jo
Features Editor
I loved quizzing Kat the pilot this month, but I'm definitely not ready to swap my hatchback for a 747 just yet.

What's in store

Check out just a small selection of the questions answered in this issue of How It Works...

How do archers take aim and fire with physics? **Page 40**

Where can you find this strange landscape? **Page 64**

How do diesel engines work to power your car? **Page 24**

How do archaeologists use drones and robots? **Page 44**

Why do astronauts train underwater? **Page 83**

How luxurious was a 1950s Stratocruiser? Very! **Page 72**

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Meet the experts...

Laura Mears
Our science expert Laura takes a look at the cutting-edge medical breakthroughs that will change as many lives as they save. Read all about the exciting developments on page 26 – you'll be blown away!

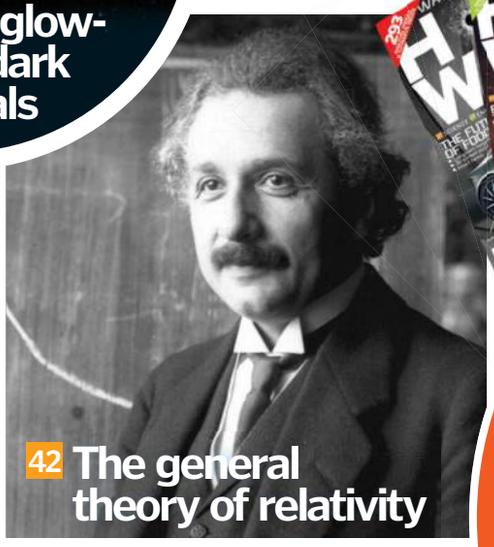
Gemma Lavender
This month, **All About Space** magazine's Gemma reveals why astronauts train underwater and tells us all about Tim Peake's exciting mission to the ISS.

James Hoare
The Editor-In-Chief of **All About History** goes back to the Victorian era this issue in a feature debunking the supernatural. Discover the dastardly tricks the charlatans used on page 68.

Ella Carter
Animal expert Ella shines a light on the creatures that can glow in the dark (page 58). You won't believe the incredible ways scientists are using this to benefit humanity!

Ceri Perkins
Delving into the tech that modern day archaeologists use, Ceri discovered plenty of drones, robots and deep-sea exosuits, but there's not a bullwhip in sight!

WARSHIPS



REGULARS

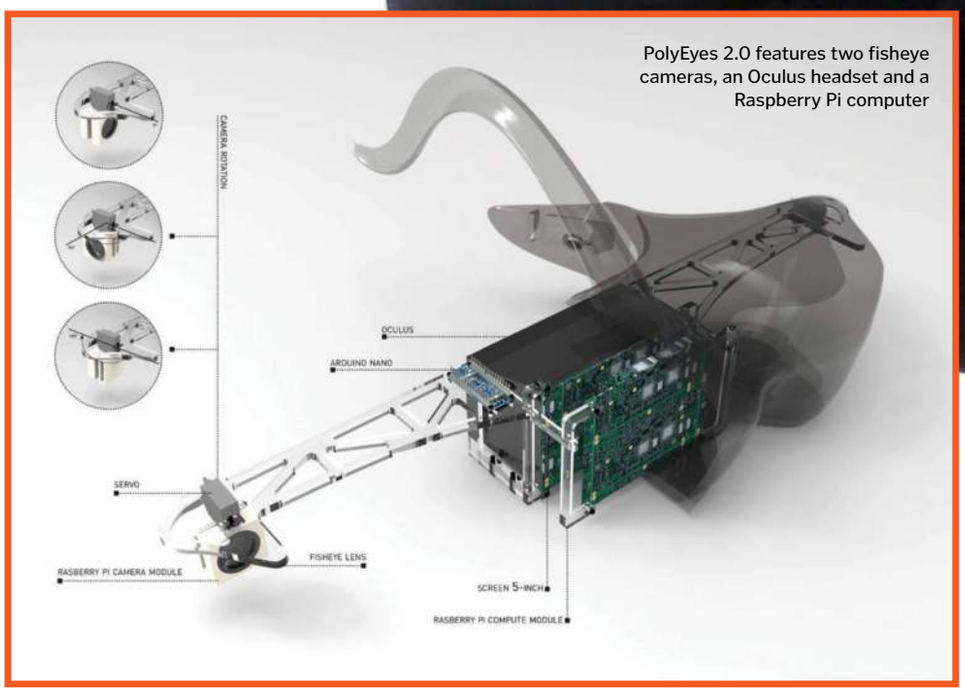
How you can get chameleon vision

This headset gives you a 180-degree view of the world around you

Known for their colour-changing skills, chameleons also have incredible eyes that can point in two different places at once, enabling them to see in all directions. It's an impressive party trick, but now an augmented reality headset could let us do the same. PolyEyes 2.0 has been developed by the Interactive Architecture Lab to upgrade the human range of vision, taking inspiration from another animal, the hammerhead shark, for its striking design.

The wide headset, also known as a Hammerhead Vision System, features a small, clear dome containing a rotating camera with a fisheye lens on each side. These act as the eyes, with each one feeding its footage to a Raspberry Pi computer module, which then displays it on an Oculus virtual reality headset. The screen you see displays the view from each camera side-by-side with a slight overlap in the middle, giving you 180-degrees of vision without having to turn around.

The headset has been developed as part of the Polymelia Project – a team of researchers who are designing a suit that would enable the wearer to share their external stimuli with another person. They explained: "We think of the body as the original prosthesis we all learn to manipulate, so that any replacement or extension becomes part of a continuing process of upgrading the human entity."



PolyEyes 2.0 features two fisheye cameras, an Oculus headset and a Raspberry Pi computer

Chameleons are able to move each eye independently

The Polymelia Suit

For the Interactive Architecture Lab, the PolyEyes 2.0 headset is just the start of their mission to upgrade the human body. Their Polymelia Suit also features PolyLimbs, the Exoskeleton, and the Sensing Suit, which all enable the wearer to share sensing stimulus with another person. For example, two people both wearing a PolyEyes headset could share their vision and hearing with each other, even if they are in different rooms, while PolyLimbs would enable them to reproduce their own body movements through the other person's suit. The lab is even working on a Hugging Jacket that will enable one person to activate air muscles on another wearer's jacket, giving them the feeling of an actual hug. As well as providing an alternative way for us to communicate in the future, the Polymelia suit could be used for gaming and medical applications, helping people with disabilities improve their living standards by mimicking everyday activities.

The Polymelia Suit could allow you to hug your long-distance loved ones

The lightest metal ever

Boeing's new super strong material is 99.99 per cent air

The world's largest aerospace company, Boeing, has created one of the lightest metals known to science. The material is called Microlattice and it has a 3D open cellular structure made up of interconnected hollow tubes, each with a wall 1,000 times thinner than a human hair. This structure enables the material to compress and then spring back into its original shape, making it excellent at absorbing energy. Boeing even claims that an egg wrapped in the microlattice could survive a 25-storey drop unharmed, as the material would absorb the full force of the impact as the egg hit the floor.

Boeing hopes that the material can be used to make lighter and more fuel-efficient aircraft

The material was inspired by the internal open cellular structure of human bone

Microlattice is 100 times lighter than Styrofoam, and can balance on top of a dandelion

‘Death Star’ vaporises a planet

NASA has witnessed a dead star ripping apart a miniature world

With its repurposed Kepler space telescope pointing towards the scene of the crime, NASA has uncovered strong evidence that a small rocky planet is being torn apart by the intense gravity of the white dwarf star it orbits. Andrew Vanderburg of the Harvard-Smithsonian Center for Astrophysics and his team spotted a ring of dusty debris surrounding the dead star and unusual elements polluting its atmosphere, all likely remnants of a cosmic object being vaporised. “This is something no human has seen before,” said Vanderburg. “We’re watching a solar system get destroyed.”

The tiny rocky planet is slowly disintegrating as it orbits its host white dwarf star

Self-lacing shoes are a reality

Limited edition Nike Mags will feature ‘power lace’ technology

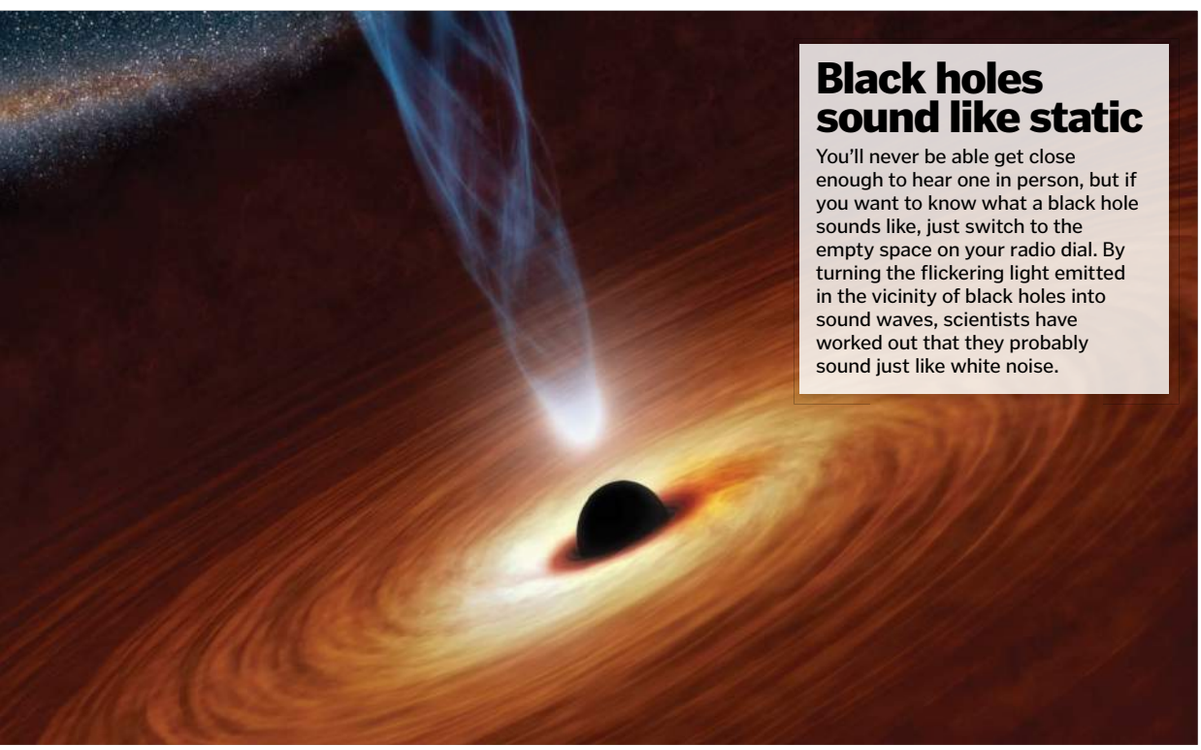
While 2015 has failed to bring us flying cars or proper working hoverboards, 2016 will see another piece of cool *Back To the Future II* tech finally become reality. Nike has revealed that the sneakers it began designing for the movie almost 30 years ago will go up for auction next year, and the first pair has already been delivered to Marty McFly himself, Michael J Fox. Unlike the Nike Air Mags released in 2011, the new shoes will feature innovative power laces, which sense the wearer’s motion to adapt on-demand.

The Nike Mags will be a limited edition release via auction, with all proceeds going to the Michael J Fox Foundation for Parkinson’s Research

10 COOL THINGS WE LEARNED THIS MONTH

Elephants could help treat cancer

Elephants have 100 times as many cells as humans, so should be 100 times more likely to get cancer. Yet only five per cent of elephants die from the disease, compared to up to 25 per cent of humans. This is because they have more copies of a tumour-suppressing gene called TP53, which researchers hope will help develop new ways to treat cancer in humans.



Black holes sound like static

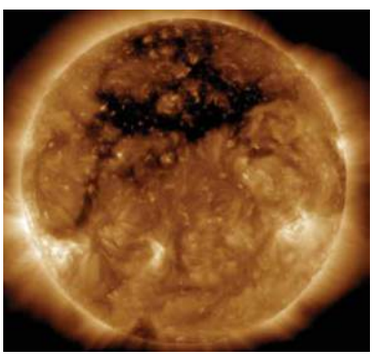
You'll never be able get close enough to hear one in person, but if you want to know what a black hole sounds like, just switch to the empty space on your radio dial. By turning the flickering light emitted in the vicinity of black holes into sound waves, scientists have worked out that they probably sound just like white noise.

Smart missiles can change course mid-flight

With unmanned drones becoming increasingly popular in military combat, the US Army has developed a new way to blast them out of the sky. The Enhanced Area Protection and Survivability system uses a 50-millimetre (two-inch) cannon to launch missiles, then a controller vehicle on the ground can direct them towards the drone by steering their thrusters remotely.

You can un-boil egg whites

If you change your mind while preparing your breakfast, then all you need is a 'vortex fluid device'. This machine has been developed by scientists to spin boiled eggs at high speed. The stress of the spinning causes the proteins in the egg to re-fold, reverting the egg white to its raw state. Outside of the kitchen, this technique could have useful applications for drug development, as proteins in drugs often misfold.



There was a hole in the Sun

Don't worry, our source of heat and light wasn't in danger of breaking into pieces. The hole was actually in the Sun's magnetised atmosphere, called the corona, and it's a fairly regular occurrence. It's caused when magnetic field lines protruding from the Sun's interior open up, enabling hot plasma to escape the corona and enter space. If this plasma reaches Earth, it can intensify the colourful auroras we see in the sky.

Butterflies are shrinking

Warmer summers in Greenland are increasing the metabolism of the island's butterflies, causing them to shrink. Unlike humans, who use more energy when it's chilly, cold-blooded butterfly larvae need more energy in higher temperatures. As they have struggled to find enough food to maintain the energy levels needed for the warming climate, their growth rate has slowed, resulting in smaller larvae and therefore smaller adult butterflies.

Reading out loud helps you remember

Whether you're revising for a test, or trying to learn your shopping list, reading it aloud can help you remember. However, researchers have now found that reading it to a friend is even better, as your brain can use multisensory information related to the exchange, as well as information about how you produced the words, when trying to recall what you said.

Lexus made a working car out of cardboard

Using just 1,700 sheets of cardboard, a steel and aluminium frame, an electric motor and some clever 3D modelling, Lexus has built a drivable, life-size replica of its IS saloon car. Just don't try to drive it in the rain.

This tiny camera can squeeze in 16 lenses

Light's L16 camera contains 16 separate lenses and sensors. When you pinch and zoom using the touchscreen, ten of these lenses capture images within the desired focal range. These pictures are then stitched together to create one big photo with an up to 52-megapixel resolution.

Most mammals take 21 seconds to pee

An elephant's bladder can hold five gallons of urine, while a cat's can hold just five millilitres, but both take the same amount of time to empty. Scientists found that larger animals have longer urethras, giving the urine more of a gravitational boost on its way out. This helps it flow faster so the bladder empties in just 21 seconds.

DAY IN THE LIFE OF

Airline pilot

Do you have what it takes to deliver holidaymakers safely to their destination?

When your office is the cockpit of a jumbo jet, no two days at work are the same. You could be flying off to Miami one week, and jetting half way around the world to Sydney the next, with the chance to explore exotic destinations in between shifts. Although there's no doubt that it's an exciting job, the life of a pilot is also hard work. From the demanding training to the tough night flights, there's a lot of planning, preparation and procedures involved in flying an aircraft full of people around the globe.

Flying from London to Los Angeles

REPORT TO CREW ROOM
8am GMT

90 minutes before take off, the pilot reports to the crew room to meet the cabin crew and their co-pilot(s), possibly for the first time, for a briefing about the flight ahead. They then print out the flight plan along with details of any weather systems and airfields that they may need to divert to in an emergency, along the route.

DIVIDE UP ROLES
8:20am GMT

While in the crew room, the pilots decide who is going to be 'pilot flying', the one who does the take-off, landing and monitoring of the autopilot system, and 'pilot monitoring', the one who does the paperwork, radio calls and any other administrative tasks. They usually take it in turns so everyone gets a chance to do the take-offs and landings.

AT THE AIRCRAFT
8:30am GMT

After a short walk or bus ride to the aircraft, the pilots complete a walk-around to make sure everything is in the right place and sign for the aircraft to take it off the engineers or previous crew. Once on board, they switch on the power systems and make sure all the dials and buttons are in the correct position.

The pilot boards the plane an hour before departure, to prepare for the journey

"Any adjustments a pilot makes to the flight deck systems have to be checked by their co-pilot"

The plane can be landed manually or with the autopilot system, depending on the conditions

PREPARE FOR TAKE-OFF
8:45am GMT

The flight route is entered into the Flight Management Computer, basically the aircraft's sat nav, and then the 'pilot flying' conducts a brief on what to expect from take-off, covering any actions that may need to be taken in the event of an emergency. After gaining permission from air traffic control, they then taxi the aircraft onto the runway.

TAKE-OFF
9:30am GMT

After take-off, when the aircraft reaches cruising altitude, the autopilot system is activated to hold it straight and level. To adjust speed or altitude, the pilot inputs the information into the autopilot so that it can carry out the necessary actions. Throughout the flight, 'pilot flying' keeps check of the flight deck systems, while the co-pilot keeps a log of any actions.

LANDING
7pm GMT / 11am PST

An hour before landing, the pilots conduct a descent brief to discuss the arrival route, weather and alternative landing options in case the destination airport becomes unavailable due to adverse weather conditions or runway closures. If the visibility is good, the pilot will land using the manual controls, otherwise the autopilot will be used to conduct the landing.

ON THE GROUND
8pm GMT / 12pm PST

Once the aircraft has taxied back to the airport terminal and all of the passengers have disembarked, the pilots then put the controls back into their correct positions and switch off the aircraft's power. They can then leave, but must pass through customs and immigration just like everyone else before travelling to their hotel.

TIME TO EXPLORE
10pm GMT / 2pm PST

The crew could get to spend anywhere between one and four nights at their destination before having to fly back again. If it's a short stay, pilots will focus on resting before the night flight home, but for longer trips, they may meet up with the rest of the crew to explore the area or simply soak up some sun.

The pilot has the best seat in the plane for capturing stunning airborne views; these are some of Hodges' favourites

How to become an... *Airline pilot*

The qualifications, skills and training you need to get behind the controls

Education

- Five GCSEs (or equivalent), including science and maths, at grade C or above
- Fluent in English (both written and verbal)

Requirements

- Aged 17 or over
- Minimum height: 1.58m (5.2ft)
- Maximum height: 1.91m (6.3ft)
- Pass criminal record check
- Pass medical tests

Training

- Pass 14 exams with a score of 75 per cent or more. Exam topics include aircraft performance, mass and balance, general navigation, air law and meteorology
- Gain flying experience in light aircraft and twin aircraft
- Complete training in a commercial aircraft simulator
- Accumulate around 200 hours flying time in aircraft and simulator

You are now a fully qualified pilot!

18 months

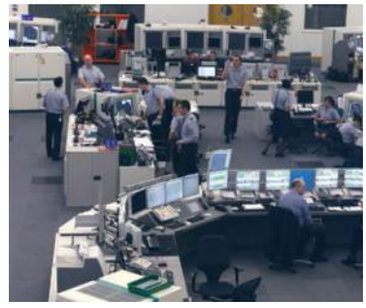
THREE OTHER JOBS IN THE INDUSTRY

Aircraft engineer

Commercial jets are incredibly complex machines, so designing and maintaining them requires a lot of skill. It is the job of an aircraft engineer to make sure the plane is safe to fly every time, examining it regularly and fixing any problems when they arise, ranging from minor faults to major structural repairs. To be an aircraft engineer, an interest in science and maths is key, and problem solving and critical thinking skills are also very useful. Most aircraft engineers hold a degree in engineering and must then be licensed to maintain aircraft and release them into service.

Flight planner

Also known as flight dispatchers, flight planners are tasked with finding the safest and most efficient route for an aircraft to reach its destination on schedule. Along with the pilot, they are legally responsible for the flight's safety, and so must consider weather systems, payload weight, fuel load and a number of other factors when working out the best route. Then, when the aircraft is in the air, they also monitor its journey, communicating with the pilot if any changes need to be made, so quick thinking and an ability to work under pressure are crucial.



Air traffic controller

Before a flight can leave the ground, its flight plan must be evaluated by air traffic control to ensure its safety in relation to traffic patterns. Controllers in the airport tower then coordinate the aircraft's route to the runway and clear it for take-off, before handing it over to the regional control centre. There, controllers monitor the aircraft through controlled airspace, communicating with the pilot at regular intervals before guiding them in to land. It's a demanding job, so an ability to handle pressure and adapt to changing situations is important.

In the cockpit

From popping ears to stunning views, what is life like for an airline pilot?

Hodges is a pilot for Virgin Atlantic, flying to over 200 destinations worldwide

When she first sat in a glider at the age of 17, Kat Hodges knew she wanted to become a commercial pilot. She now flies the Boeing 747-400 all over the world for Virgin Atlantic and helps mentor the trainee pilots following in her footsteps. We caught up with her at London Gatwick Airport to find out what's it's like to have a career at 30,000 feet.

What are the most important qualities you need to become a pilot?
Thinking of my day-to-day job now, an ability to get on with people and work as part of a team are probably some of the key things. Obviously having an appreciation for the technical side, an ability to learn and capacity to remember things are very useful, but it isn't just you flying the plane. There could be three of you in quite a small space, then you've also got up to 15 cabin crew and the people who service the aircraft. We interact with all these people, and you're going to get the best out of any day by working together as a team.

Do you ever get nervous or scared when you're flying?
Never. I thought I would the first time I flew a commercial airplane but the simulator is so realistic. It's basically the front end of an airplane and the graphics are so good that it's easy to forget about the rest of the aircraft. I remember it being a bit of a surprise on my first day when I looked back through the door and there were all of these faces. The simulator does a very good job of desensitising you from the nerves.

What is your favourite thing about the job?
I absolutely love it when I've flown a flight, everything has gone according to plan and I walk away knowing I have made a lot of people really happy. We get a lot of feedback during the flight from the cabin crew saying things like "there's a couple in upper class who are off on their honeymoon," and that's great. Otherwise, it could be quite easy to fragment yourself from the real purpose of what you're doing, which is bringing families together, taking people on holiday and helping business happen. Then there's also the view out of the office window. I could bore you senseless with all the pictures I've taken of clouds and sunsets!

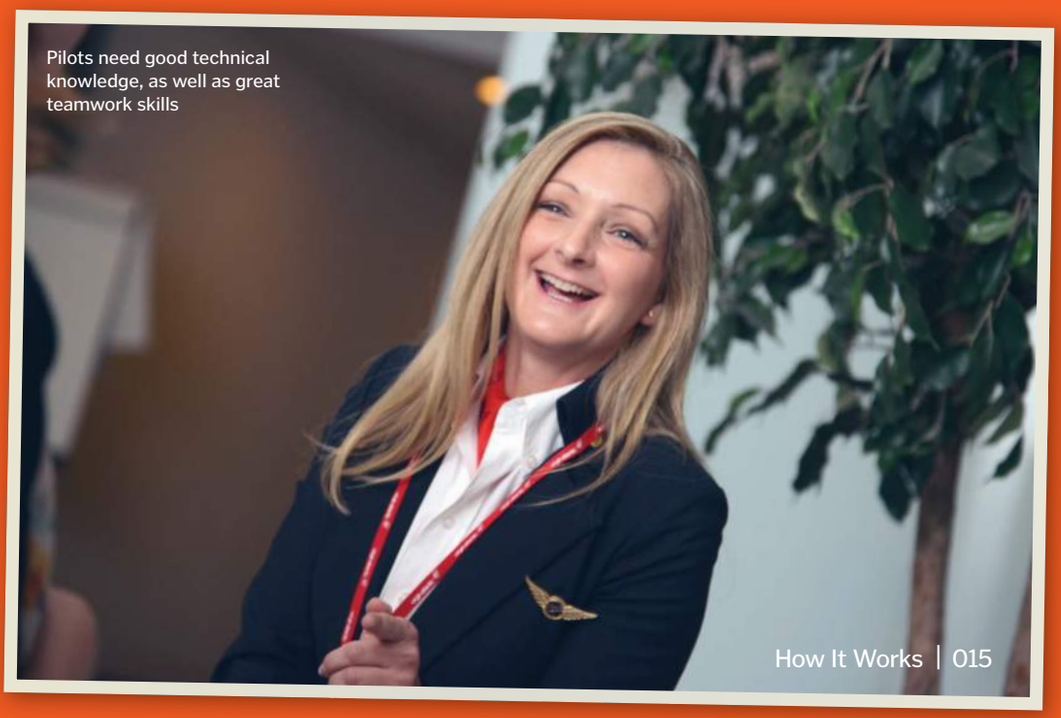
"I could bore you senseless with all the pictures I've taken of clouds and sunsets!"

What are the worst parts of the job?
I think any shift-worker who has to work nights is going to tell you that staying up late is hard. We often fly home at night, so you take rest as best you can. I find that staying fit, eating light meals and chatting to the crew helps keep you awake. I can probably be a bit grumpy on landing days, though.

Do your ears pop every time you fly?
No, your ears only pop if you have a cold or your sinuses are slightly inflamed. So it's a sign that you might not be well.

What do you think of airplane food?
I think the food is excellent. I quite often bring something with me though, particularly if I'm down route and like a local delicacy. I'm very fond of jerk chicken, for example, so I will bring a little portion to have for my supper on the way home, as a special treat.

What advice would you give to anyone wanting to become a pilot?
I would say to do a lot of research, go and visit flying schools and look at the cadet programmes that are available. Also talk to other students at flight schools, go to any flight training exhibitions that you can and ask a lot of questions!


Pilots need good technical knowledge, as well as great teamwork skills

WARSHIPS

HOW THE NAVY OF THE FUTURE WILL RULE THE WAVES

Illustrations by Tobias Roetsch

Despite what the popular board game suggests, naval warfare isn't as easy as shouting a series of coordinates until the enemy's vessel is obliterated. A real-life game of battleships is all about military planning, precision and firepower.

Early battleships launched during the late 19th and early 20th century carried enormous guns capable of launching projectiles across the ocean surface to targets thousands of metres away. To defend themselves against enemy ships with equal firepower, they needed to be heavily armoured too, with thick steel plates encasing their huge hulls.

During World War I, battleships became dominant naval weapons. Prior to the Great War, Germany challenged the Royal Navy as the most powerful fighting fleet, Britain hit back with the revolutionary HMS Dreadnought, kick-starting a naval arms race. However, by the outbreak of World War II, superior aircraft and submarine weapons had rendered the battleship obsolete, enabling the aircraft carrier to seize its position as capital ship of the fleet.

Navies could now attack targets within a much greater range than existing naval guns could reach, simply by sending out aircraft to deliver the devastating firepower instead. As a result, the role of warships became more about close-range combat, with destroyers and cruisers carrying fewer and smaller guns, enabling them to be much lighter and more easily manoeuvrable when seeking out enemy targets.

Today, navies have an assortment of warships that they can call upon to tackle any situation, whether it's providing security for other vessels, responding to humanitarian disasters or attacking an enemy submarine hidden beneath the water. As new ships are developed, speed, efficiency and cost-effectiveness are key, with increased automation helping to shrink crew sizes.

For fleets of the future, only a few crew members may be needed on board, as computers, drones and unmanned boats carry out the difficult and dangerous duties instead. Advancements in technology could also bring back battleship-level firepower, with electromagnetic railguns and even laser weapons replacing heavier, more expensive firearms in the navy arsenal.

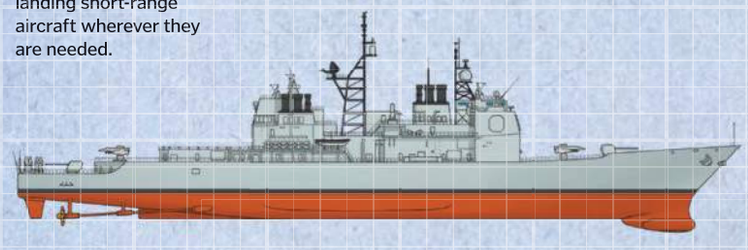
If these visions for future navy vessels come true, it could be even harder to catch up with, let alone sink, your opponent's ship in D7, before they fire their laser at your aircraft carrier in B10.

Meet the fleet

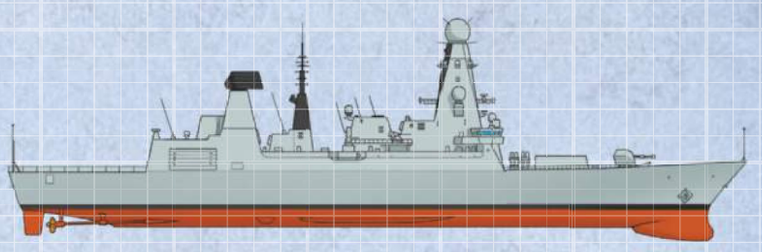
*Not to scale

The types of naval warships being called into battle today*

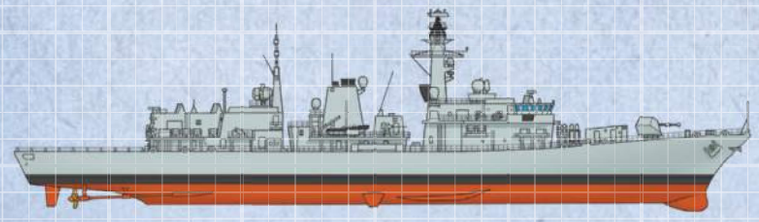
Aircraft carrier
These enormous airbases at sea are equipped with a flight deck for launching and landing short-range aircraft wherever they are needed.



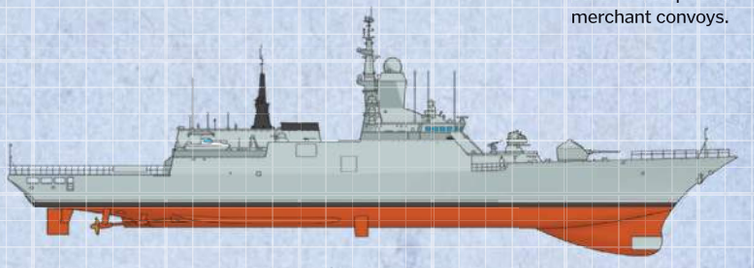
Cruiser
The second largest warships after aircraft carriers, cruisers have guided missile systems for taking out targets above, below or on the waves.



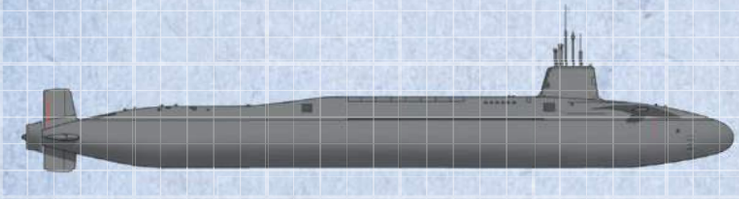
Destroyer
These are slightly smaller, and therefore more agile, than cruisers, and can provide protection from a variety of targets.



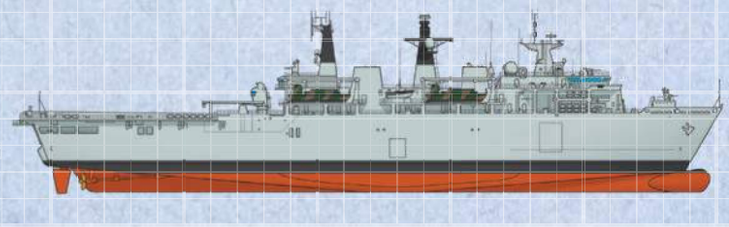
Frigate
Designed mainly to hunt submarines, frigates are generally smaller than destroyers and are used to protect other warships and merchant convoys.



Corvette
The navies of countries bordering small seas instead of large oceans often use small, lightly-armed corvettes to patrol their coasts.



Submarine
These stealthy underwater vessels are silent hunters capable of surveillance and reconnaissance missions, as well as launching missiles.



Amphibious assault ship
With a primary objective to get troops and their equipment to shore, these vessels can launch helicopters and other amphibious landing craft.

"As new ships are developed, speed, efficiency and cost-effectiveness are key"

Illustrations by Tom Connell/Art Agency

The future of warships

What will naval fleets look like in the year 2050?

The Royal Navy has asked this very question, challenging young British scientists and engineers to design the fleet of the future. Their vision is the Dreadnought 2050 concept, a high-tech trimaran vessel built for speed, stability and efficiency. Named after the 1906 HMS Dreadnought, which was also a revolutionary vessel in its day, the sleek ship is almost fully automated, cutting today's crews of 200 down to 50 or 100 members.

Renewable energy technology could also give the ship unlimited range, allowing it to sail the world without stopping to refuel, and advanced weapons will enable immense firepower in battle. While some of the technologies envisioned for the Dreadnought 2050 are not yet achievable, others could realistically be incorporated into future designs, lowering the cost and manpower needed for the next generation of warships.

Disarming technique

The tether is made from cryogenically cooled carbon nanotubes that can transmit power to the quadcopter's laser weapon and knock out enemy aircraft.

The Dreadnought 2050 concept

The Royal Navy's plans for a high-tech warship of the future

Tethered drone

Instead of a conventional mast, a quadcopter carrying sensors such as radar is tethered above the ship.

See-through shell

The hull is made from ultra-strong acrylic composites that can be turned translucent by running an electric current though them.

Flight deck

The extendable flight deck at the back of the ship can be used to launch unmanned aerial vehicles (UAVs) equipped with weapons.

The flight deck's hangar can hold weaponised drones and a helicopter

3D printing

If additional UAVs are needed, they can be constructed on board the ship using 3D printing technology.

Hypersonic missiles

Tubes running along the sides of the ship carry hypersonic missiles that can travel at over five times the speed of sound.

A garage area at the stern of the ship holds a fleet of smaller boats

Floodable garage

Beneath the extendable flight deck and its fleet of drones is a garage full of even more specialist craft. These include unmanned underwater vehicles (UUVs) that can be used to detect mines on the ocean floor, and amphibious vessels used to transport troops to and from the shore for raiding missions. When the door of the garage is opened at sea, water floods in to submerge the lower level, transforming it into a platform from which these craft can be launched and recovered. A 'moon pool' – or small hole in the floor of the garage – also enables submersibles to be deployed while the garage door is closed.

The statistics...

Dreadnought 2050

Length: 155m (508ft)
Beam (width): 37m (121ft)
Top speed: 92km/h (57mph)
Crew: 50-100
Range: Potentially unlimited

Holographic command centre

The days of pushing model ships around a map are long gone, as future naval operations will be planned using a 3D holographic command table. Located in the operations room at the heart of the ship, the table will allow commanders to rotate and zoom in to the hologram for a closer look at specific areas of the battlefield, thousands of miles away. Banks of 2D multi-functional displays can also be used to present and transmit data in real-time, while 'Google Glass-like' walls overlay additional information on a 360-degree view of the ship's surroundings.

"A high-tech trimaran vessel built for speed, stability and efficiency"

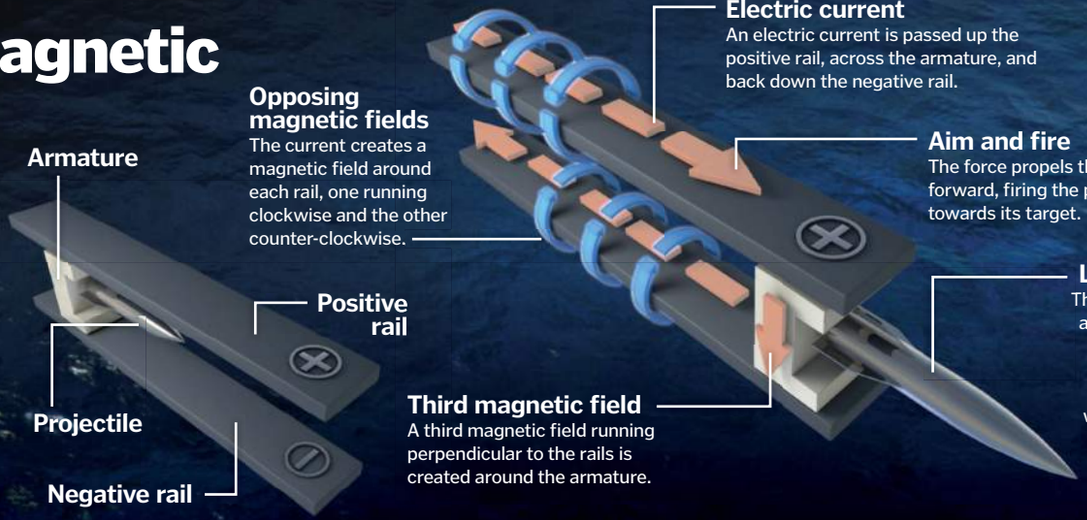
Tough exterior
The hull is coated in graphene, a strong yet lightweight material that will reduce drag for faster sailing.

Torpedo bubbles
Tubes in the outrigger hulls contain torpedoes that can travel at 556km/h (345mph), as they are encased in a bubble of gas that reduces friction.

The ship's railgun uses electromagnetism to propel its projectiles

Electromagnetic railgun

Located on the ship's bow is a high-powered railgun that uses electromagnetic effects instead of explosive chemical propellants. The US Navy's current prototype railgun can fire projectiles at speeds of over Mach 7 (8,644 km/h or 5,371mph), using kinetic energy rather than conventional explosives to inflict damage and destroy the target.



Armature

Opposing magnetic fields
The current creates a magnetic field around each rail, one running clockwise and the other counter-clockwise.

Positive rail

Projectile

Negative rail

Electric current
An electric current is passed up the positive rail, across the armature, and back down the negative rail.

Aim and fire
The force propels the armature forward, firing the projectile towards its target.

Lorentz force
The electric current and magnetic field interact to create what is known as Lorentz force, which accelerates the projectile.

Third magnetic field
A third magnetic field running perpendicular to the rails is created around the armature.

Next-gen aircraft carriers

Meet the colossal new centrepiece of the US Navy fleet

Aircraft carriers are often the capital ships of a nation's navy, helping the air and maritime forces work together to project air power worldwide. The US Navy currently has ten enormous nuclear-powered supercarriers in its fleet but a long-overdue upgrade is on its way. The first of the new Ford-class carriers, the USS Gerald R Ford, is currently undergoing the final phases of construction and testing, and is set to join the Navy's fleet in 2016. The USS Gerald R Ford, also known as CVN 78, will be similar in size to its predecessor Nimitz-class ships, but as the first aircraft carrier to be completely designed using 3D computer modelling, it will be lighter, cheaper and more powerful. Increased automation will mean between 500 to 900 fewer crew members will be needed on board and for the first time, air conditioning will be available throughout the ship, making life at sea more comfortable. The carrier can hold up to 90 aircraft at a time, but instead of launching them using the steam-powered catapults found on modern day ships, an electromagnetic launch system will be used to fire them into the air. This works a lot like a railgun but uses an aircraft as the projectile.

The USS General R Ford's command centre, known as the 'island', sits on the flight deck

"It's the first aircraft carrier to be completely designed using 3D computer modelling"

The USS Gerald R Ford will be able to load weapons and launch aircraft faster than ever before

The final weight of the ship will be over **90,000 TONS** the equivalent of **400 STATUES OF LIBERTY**

AROUND **200,000 GALLONS** of paint will be needed to cover the ship, enough to cover **THE WHITE HOUSE 350 TIMES**

10 million feet of electrical cable will be installed on board, enough to reach the **INTERNATIONAL SPACE STATION** almost **8** times over

220 AIRCRAFT can be deployed from the flight deck each day

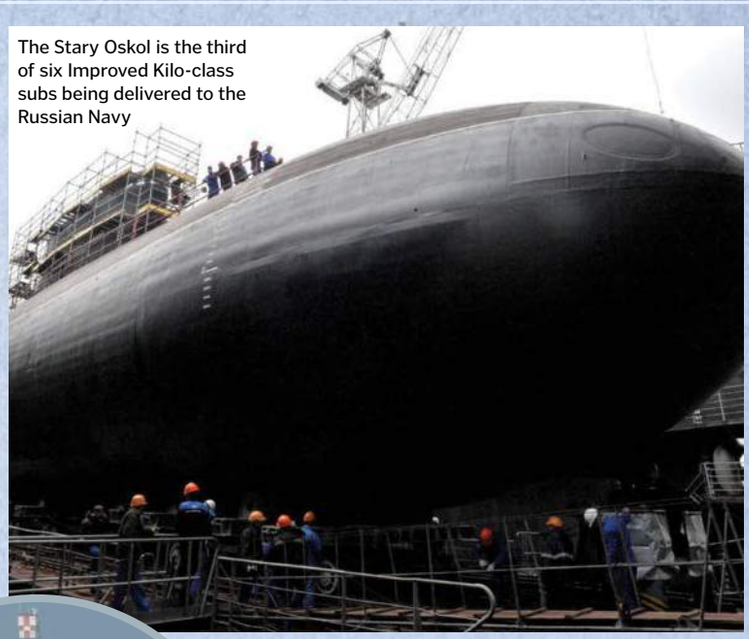
25% more than from the Nimitz-class ships

Reduced manning and maintenance will save the US Navy more than **$4 Billion (APPROX £2.6 BILLION)** over the ship's **50 YEAR LIFESPAN**

The heaviest component of the ship weighs **1,026 TONS** AS MUCH AS **6 BOEING 747 JETS** It was hoisted into place by a **1,050 TON** crane called Big Blue

Silent submarines

The stealthy 'black hole' subs that are undetectable in battle



The Stary Oskol is the third of six Improved Kilo-class subs being delivered to the Russian Navy

They may be hard to miss when on dry land, but Improved Kilo-class submarines are able to travel unseen through the depths. These diesel-electric subs are considered to be the quietest in the world, leading NATO to nickname them 'black holes' due to their low noise and visibility. Despite weighing around 4,000 tons, the subs can reach speeds of 37 kilometres (23 miles) per hour, and can patrol for up to 45 days at a time.

Once they have snuck up on the enemy, eight infrared-guided surface-to-air missiles can then be fired at targets above the water, or computer-controlled torpedoes can be deployed beneath the waves. The submarine's array of sensors mean that it can detect enemy vessels at a range three to four times greater than it can be detected itself. This surveillance data can then be used by the onboard computer to calculate firing parameters and recommend manoeuvres and weapon deployment. The six stealthy subs in this class will be patrolling the Black Sea by the end of 2016.

Drone boats

The unmanned vessels saving sailors from high-risk missions

With aerial drones already being used in military combat, it was only a matter of time before unmanned boats came onto the scene. The Royal Navy currently has a fleet of modified rigid inflatable boats (RIBs) in development that will be able to perform complex surveillance and reconnaissance missions, without putting sailors in harm's way. Using an arsenal of sensors, including a navigation radar, a 360-degree infrared camera array and a laser range finder, the vessels will be able to operate autonomously while avoiding collisions, and are expected to provide added protection for the Queen Elizabeth-class aircraft carriers once they enter service. The US Navy is also developing similar unmanned vessels that will be able to swarm and attack enemy targets, and the US defence agency DARPA even has plans for an 'Anti-Submarine Warfare Continuous Trail Unmanned Vehicle' that will be able to use artificial intelligence and sensors to hunt for enemy submarines.

Laser weapons

The souped-up laser pointer that can destroy drones with deadly accuracy

The US Navy has turned science fiction into reality by developing a real-life laser gun that can blow up targets in an instant. Although they won't be using it to fight space aliens any time soon, the Laser Weapon System (LaWS) has been successfully tested at sea, proving that it is capable of blowing up moving targets on aerial drones and small boats. The weapon, which has been installed on board the USS Ponce, consists of six commercial welding lasers joined together, and can deliver 30 million times as much power as a hand-held laser pointer. It is operated using an Xbox-style controller and can be used to simply disable a target's sensors and instruments, or destroy it completely. As well as improved accuracy, another big advantage of LaWS is its cost, as the price of firing the laser is just 59 cents (39 pence) per shot, compared to the $2 million (£1.3 million) needed for a traditional missile.

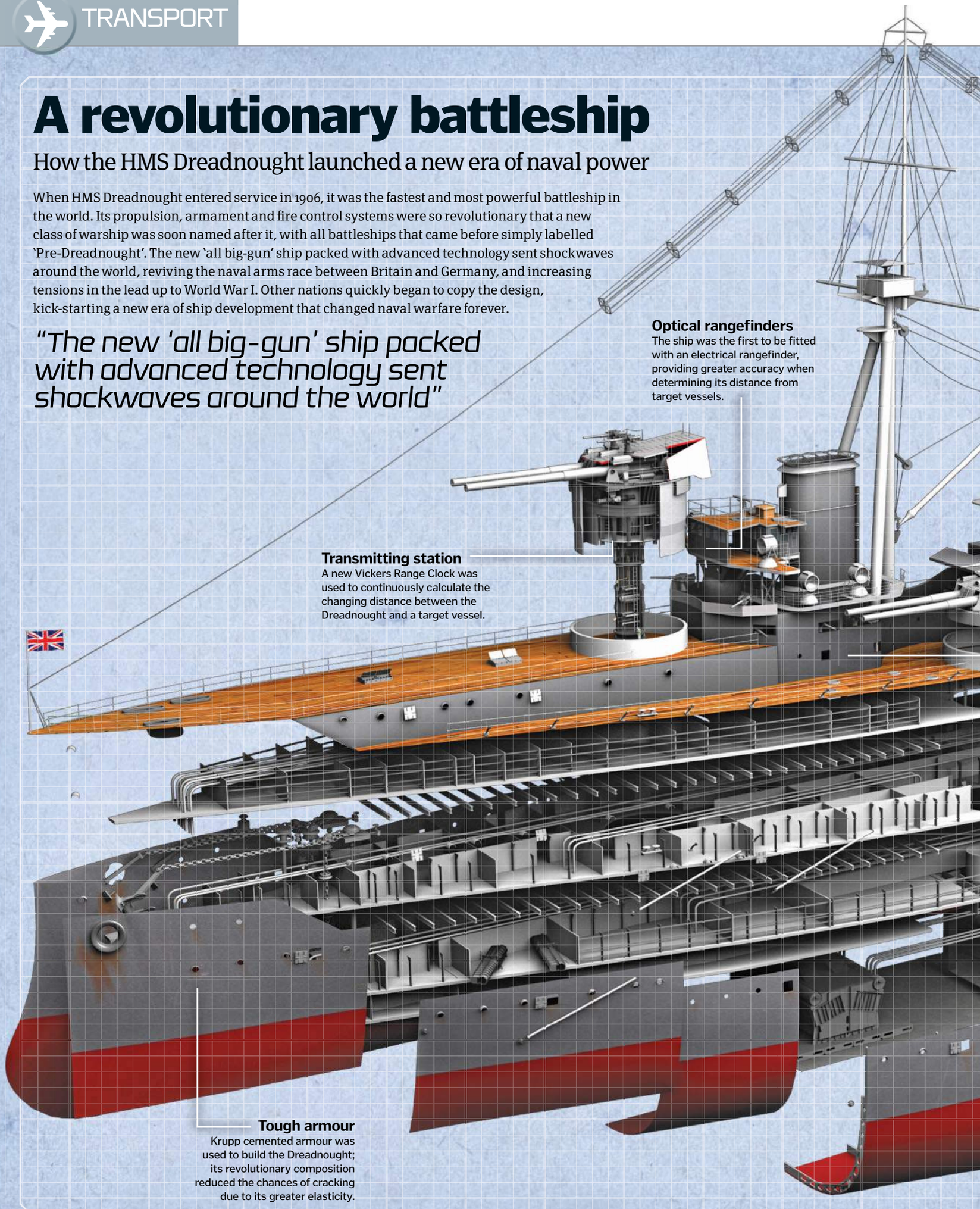
LaWS is operational on board USS Ponce and can be used to defend against unmanned targets

A revolutionary battleship

How the HMS Dreadnought launched a new era of naval power

When HMS Dreadnought entered service in 1906, it was the fastest and most powerful battleship in the world. Its propulsion, armament and fire control systems were so revolutionary that a new class of warship was soon named after it, with all battleships that came before simply labelled 'Pre-Dreadnought'. The new 'all big-gun' ship packed with advanced technology sent shockwaves around the world, reviving the naval arms race between Britain and Germany, and increasing tensions in the lead up to World War I. Other nations quickly began to copy the design, kick-starting a new era of ship development that changed naval warfare forever.

"The new 'all big-gun' ship packed with advanced technology sent shockwaves around the world"



Optical rangefinders
The ship was the first to be fitted with an electrical rangefinder, providing greater accuracy when determining its distance from target vessels.

Transmitting station
A new Vickers Range Clock was used to continuously calculate the changing distance between the Dreadnought and a target vessel.

Tough armour
Krupp cemented armour was used to build the Dreadnought; its revolutionary composition reduced the chances of cracking due to its greater elasticity.

Two of the Dreadnought's 12-inch Mark X guns ready to fire

Firepower

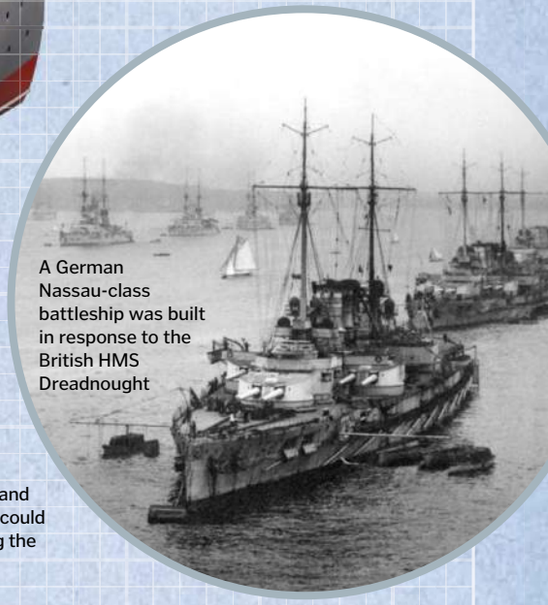
As the first all big-gun battleship, the HMS Dreadnought had astonishing firepower. Mounted on the top and sides of the ship were 12-pounder guns that could defend against torpedo boats up to 8.5 kilometres (5.3 miles) away. For more distant targets, a further five 12-inch twin-gun turrets could be fired with a range of up to 23 kilometres (14.3 miles), and as they all had identical ballistic characteristics, their firing range could be adjusted much more easily than guns of a different calibre. Plus, five 18-inch torpedo tubes could defend against attacking submarines.

Crew quarters
Officers and listed men were housed much closer to the bridge than usual to ensure they were closer to their action stations.

The statistics...

HMS Dreadnought

Length: 161m (527ft)
Beam (width): 25m (82ft)
Top speed: 39km/h (24mph)
Crew: 700-810
Range: 12,260km (7,620mi)



A German Nassau-class battleship was built in response to the British HMS Dreadnought

Fuel supply
Nearly 3,000 tons of coal and over 1,000 tons of fuel oil could be carried on board, giving the ship a range of 12,260 kilometres (7,620 miles).

Fire doors
Passageways between compartments below deck were removed and connecting doors were kept shut during combat to prevent the spread of fire or flooding.

Turbine engines
Dreadnought was among the first battleships to use steam turbine engines, helping it reach the impressive speed of 39km/h (24mph).

Life of the Dreadnought

Despite being the dominant battleship of its era, HMS Dreadnought never actually managed to sink another battleship. The only major piece of action it saw came in 1915, when it was patrolling the North Sea during World War I. As a German SM U-29 submarine broke the surface ahead of it, a chase began. Eventually Dreadnought rammed into it and became the first battleship in history to sink a submarine.

While undergoing a refit in early 1916, it missed the now infamous Battle of Jutland, which saw the largest confrontation of battleships whose design the Dreadnought had inspired. The HMS Dreadnought was decommissioned after the end of the First World War and eventually sold for scrap, but its iconic status as the most revolutionary battleship of its age lives on.

Illustration by Alex Pang

Diesel engines

The power behind the biggest machines on the road


Accidentally filling up a diesel car with petrol can damage the engine, so don't switch on the ignition!

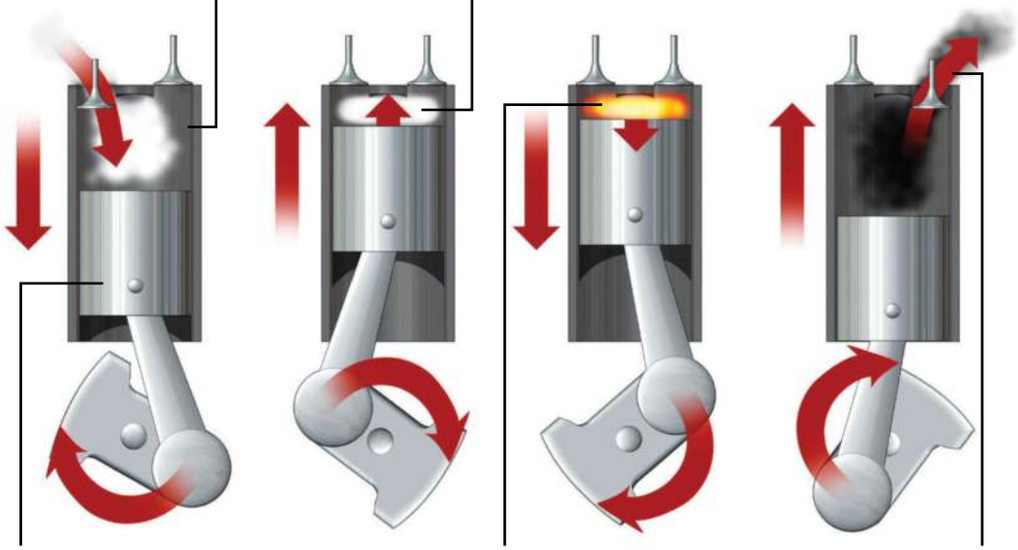
At face value, a diesel internal combustion engine looks almost identical to that of its petroleum-powered counterpart. However, a diesel engine operates differently to that of a petrol engine, and it's all to do with how the fuel is ignited in the combustion chamber.

An internal combustion engine works by creating mini explosions in the combustion chamber of each cylinder. This pushes a piston downwards, spinning the crankshaft it's attached to (via connecting rods). The rotational energy from the crankshaft is then transferred to the vehicle's wheels, propelling it forward. Most internal combustion engines used today are four-stroke, which means a four-step process takes place inside the combustion chamber: intake, compression, combustion, and exhaust.

Broadly speaking, both diesel and petrol engines follow the four-stroke cycle, though there are huge differences when it comes to 'combustion', which happens when the piston is at the top of the cylinder. In a petrol engine, the spark plug ignites the petrol and air mixture, whereas in a diesel engine, fuel is injected at high pressure into the hot, compressed air in the cylinder, causing it to burn rapidly and forcing the piston down.

Cylinder
Engines usually contain multiple cylinders, where the intake, compression, combustion and exhaust processes take place.

Compression
As the crankshaft spins round, the piston is pushed back up, forcing the air to compress.



Intake
Air is forced into the cylinder at high pressure via an intake valve, forcing the piston down.

Combustion
The compression heats the air, so much so that when the diesel fuel is injected, it instantly ignites. The explosion forces the piston back down.

Exhaust
As the piston goes back down the cylinder, the exhaust valve in the top opens to let out the 'spent' exhaust gases. The cycle starts again with 'intake'.

The disaster-resistant bridge

Malaysia's new 24-kilometre bridge can withstand tsunamis and earthquakes

Few man-made structures can survive the unforgiving wrath of Mother Nature, but the Second Penang Bridge in Malaysia can lay claim to just that. Innovative technology used in the construction of the bridge means it is both earthquake- and tsunami-resistant, a life-saving selling point for this natural disaster-prone area of the planet.

The bridge, awarded the 2015 Brunel Medal by the Institution of Civil Engineers, is rooted into position by a series of wide, pre-cast concrete pylons mounted at a world record depth of 127 metres (417 feet). Cables are connected to the pylons using third-generation saddles (the blocks at the top of the bridge over which the cables pass), improving their structurally efficient hold. The 24-kilometre (14.9-mile) bridge, which will take motorists approximately 20 minutes to cross, has a curved appearance when viewed from above. This is to reduce traffic accidents, forcing drivers to reduce their speed and concentrate on the curve of the road – keeping the area safe from erratic drivers as well as the elements.


In an area prone to natural disaster, the Second Penang Bridge will save lives


The bridge is the longest sea crossing in Southeast Asia

Dreamstime/Thinkstock/Science Photo Library

Eco-friendly aircraft

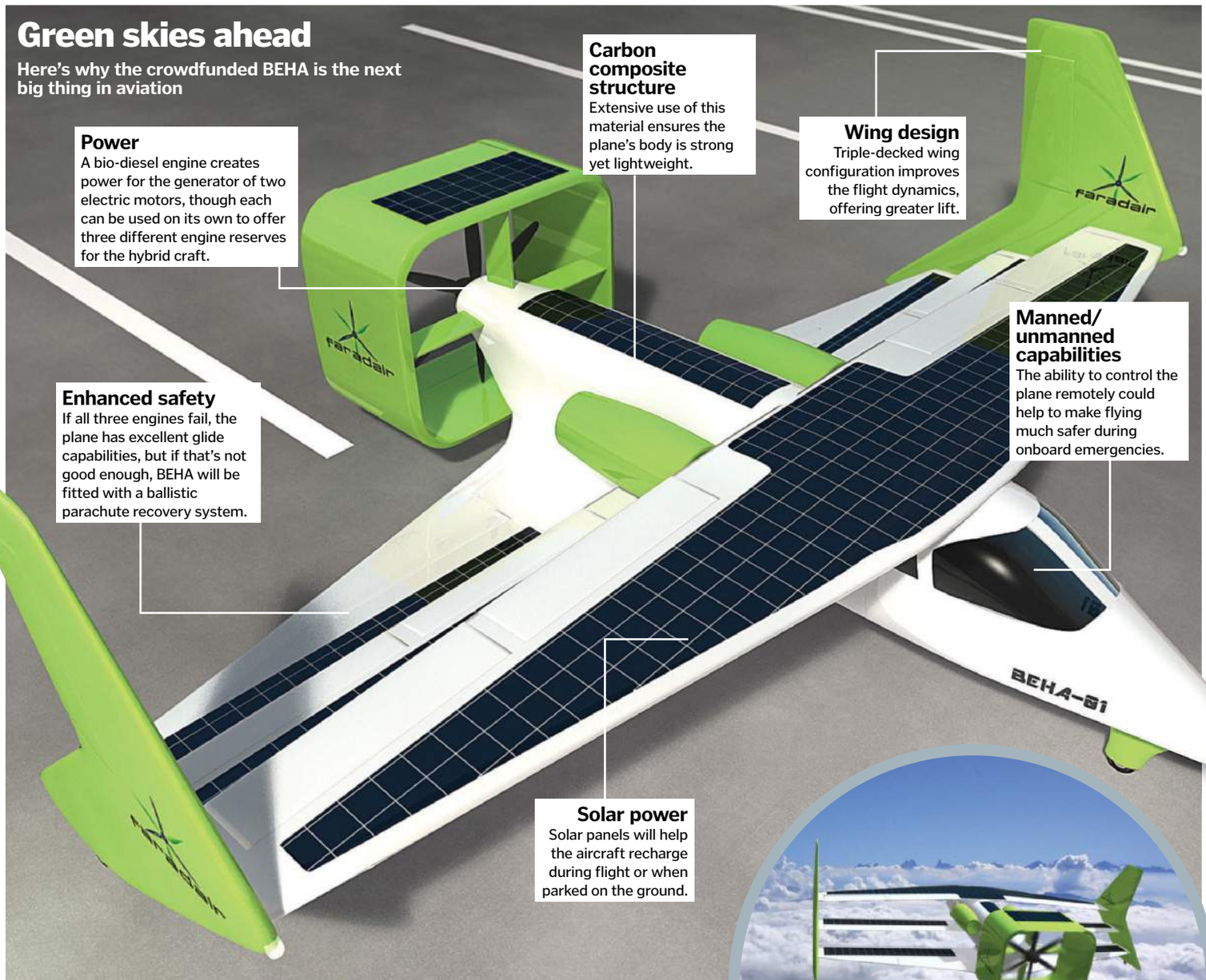
The future of aviation is designed to be lightweight, cleaner and quieter

In the last decade the travel industry has witnessed a marked swing in favour of more environmentally friendly vehicles. While the likes of Tesla have pioneered hybrid and electric technology in road vehicles, a drive for more efficient travel has also taken to the skies. When it comes to reinvention of light passenger aircraft, there are few more innovative than the Bio-Electric-Hybrid-Aircraft (BEHA).

The product of Faradair Aerospace – in partnership with Prodrive and Cranfield University – seeks to lower costs while offering safer operational capability with lower noise and emissions. There are three engines on board BEHA, with one bio-diesel engine effectively powering two electric motors – though the plane can be flown purely on the bio-diesel reserve engine. This improves its safety in the event of engine failure. Solar skin panels will ensure greater energy generation and recovery during flight, in a bid to reduce emissions.

What's more, the plane can take off and land on pure electric energy for reduced flight noise, ensuring it can be used around the clock, even in urban areas where night restrictions may apply. It's not just the plane's power source that breaks with tradition, either. Made entirely from carbon fibre – usually found on supercars such as the McLaren P1 – BEHA is designed to be lightweight yet strong.

Lift-off won't be for a while yet, as the prototype is still in development, but the sky's the limit according to Faradair. "We have a vision of BEHAs flying in general private aviation, in wildlife monitoring and conservation duties, and many more opportunities," says the manufacturer. "Our goal is to achieve all the benefits of air travel, with minimal impact to the environment around us."



AMAZING NEW MEDICAL TECH!

MIRACLE SCIENCE

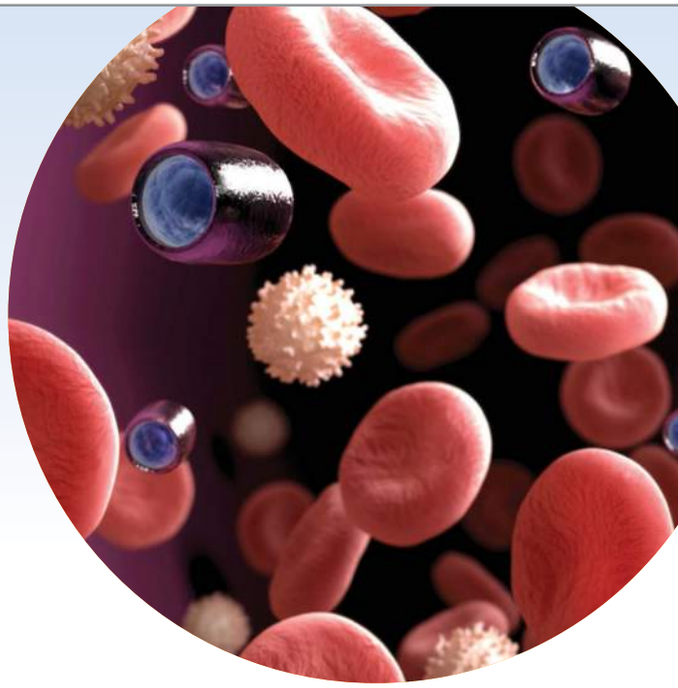
REVEALED: THE BREAKTHROUGHS THAT WILL SAVE YOUR LIFE

Modern medicine would seem miraculous to people living less than 100 years ago, but the advancements on the horizon are even more incredible. Scientists and engineers from a wide range of different specialisms are bringing the latest developments together to create an array of new medical technologies that could completely transform the way we diagnose, treat and even cure disease.

Nanotechnology is taking medical treatment down to the molecular scale, focusing on the minute machinery that keeps the body ticking over, while stem cells could provide a renewable source of replacements for every cell in the human body. Personalised medicine promises to tailor treatments to each patient's individual genetic profile, and advances in neuroscience, computing, robotics and electronics are allowing advanced prosthetics to respond directly to commands sent by the brain. Vaccinations could one day be delivered painlessly by thousands of microscopic projections, while custom combinations of vitamins or drugs could be printed into convenient daily pills.

We can't be sure which of today's cutting-edge techniques will make it to the medical clinics of the future, but with technology moving this rapidly, there are certain to be more medical 'miracles' just around the corner.

Nanomedicine



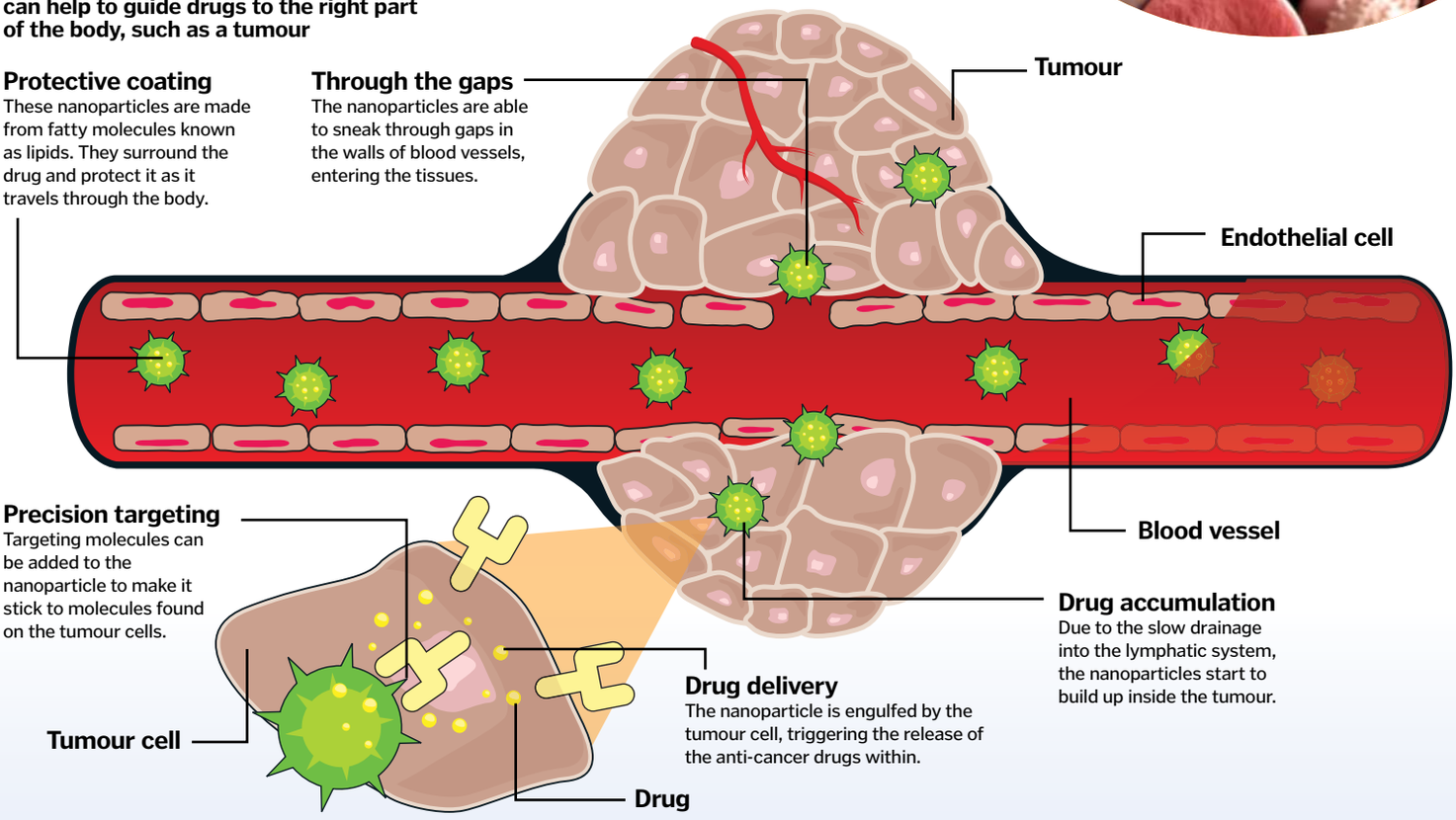
The molecular machinery that keeps the human body running is built on a nanometre scale. Haemoglobin molecules (the proteins that carry oxygen in your blood) are roughly 5 to 7 nanometres in diameter – that's about 10,000 times smaller than the width of a human hair!

Nanomedicine attempts to interact with this miniature world using materials that measure less than 1,000 nanometres across. Down at this tiny scale, scientists hope to develop high-precision nanotechnology that could repair or replace damaged cell components.

Nanomaterials have already entered the clinic, where they are being used to make capsules that carry tiny packages of drugs into the body. Some capsules help to protect the drug from being broken down as it travels to the right part of the body, and others assist with targeting, ensuring that the treatment gets to the right place.

Nanomedicine in action

Nanoparticles made from fatty molecules can help to guide drugs to the right part of the body, such as a tumour



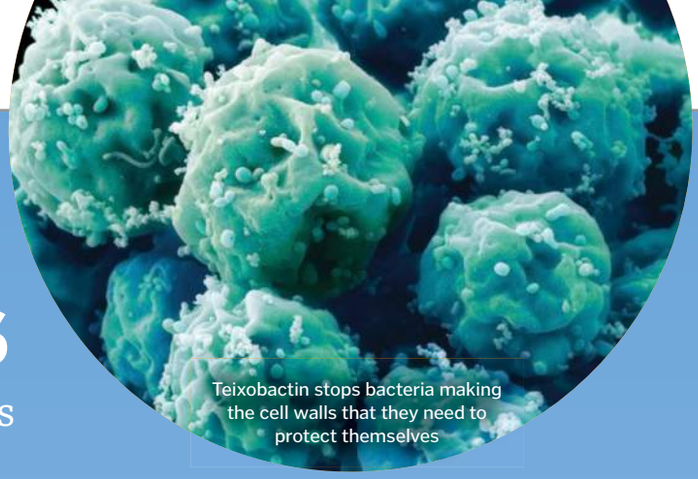
Detecting diseases

Inspired by the Star Trek Tricorder, the Qualcomm Tricorder XPRIZE offers $10 million (over £6.5 million) to a team able to design a portable medical analyser. The aim is to be able to detect 16 common diseases, such as anaemia, diabetes and tuberculosis, and to monitor five vital signs, including blood pressure, heart rate and oxygen saturation. Technology like this could make diagnosis much simpler, potentially even allowing people to monitor their own health at home.

The competition has been running since 2012, and the winner is due to be announced in 2016. Finalists include the Scanadu Scout, which can monitor vital signs like pulse and blood pressure when held next to the head, and the rHEALTH sensor, which can detect pneumonia or even Ebola from a tiny drop of blood.

Miniature 'lab-on-chip' technology allows portable medical testing

Regenerating damaged tissues



Teixobactin stops bacteria making the cell walls that they need to protect themselves

With incredible capacity for regeneration, stem cells have the potential to replace every cell in the body

Most of the cells in your body are highly specialised; each is dedicated to its individual role, and once it has committed to becoming a certain cell type, the decision is permanent. Stem cells, however, have not yet chosen a specialism. Instead, they support growth and repair, and are able to carry on making copies of themselves long after most other adult cells would have stopped dividing. Each of those copies can rest, make more copies, or begin the process of transforming into a specialist cell.

The specialism that the stem cell chooses varies based on the signals it receives, and depending on the type of stem cell that it is – an embryonic stem cell, or one of the many different kinds of adult stem cell. Embryonic stem cells are the most powerful; they are found in the developing embryo and, with the right signals, can transform into any cell in the human body.

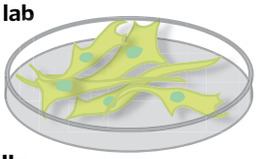
Given these incredible properties, it is no wonder that stem cells are receiving a lot of attention from the scientific community. Doctors already perform stem cell transplants to replace lost bone marrow, and stem cells are used to create skin grafts. In the future, it is hoped that they will be used to repair damaged tissues inside the body, or even to rebuild entire organs.

Growing stem cells

There are two main approaches to producing human stem cells in the lab

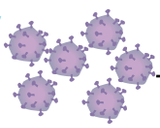
Method 1: Induced pluripotent stem cells

Adult cells can be 'reprogrammed' by scientists to behave like embryonic stem cells.



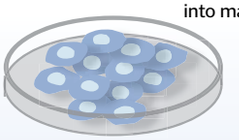
Adult stem cells

Adult stem cells have already made some commitments, and in this state, can only go on to make certain cells.



Reprogramme

Adult stem cells can be 'reprogrammed' back to an earlier state using viruses, allowing them to transform into many more cell types.

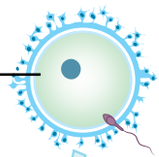


Change culture conditions

Stem cells can be encouraged to become different types of specialised adult cells by varying their conditions.

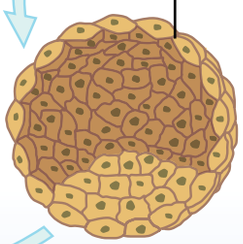
Method 2: Embryonic stem cells

These powerful stem cells are found in human embryos, but research is limited in many countries due to ethical concerns.



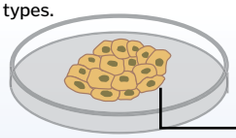
Fertilised egg

The cell that is formed when a sperm and egg combine must go on to produce all of the cells in the body.



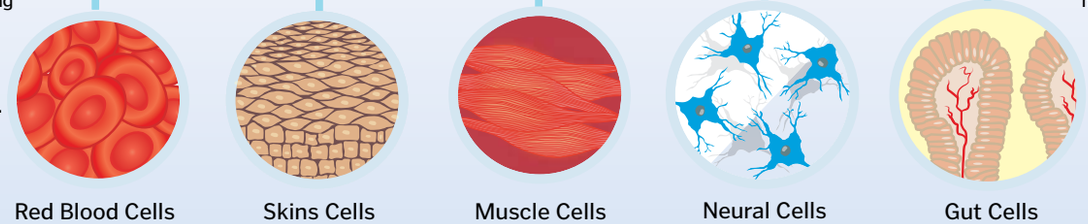
Blastocyst

After around a week the embryo is a ball of cells surrounding a cluster called the inner cell mass. The stem cells in this bundle have the potential to become any cell in the body.



Culture

The embryonic stem cells are harvested, and given signals that tell them to make copies of themselves.



Red Blood Cells | Skins Cells | Muscle Cells | Neural Cells | Gut Cells

IS STEM CELL THERAPY A GOOD IDEA?

There are arguments for and against using stem cells for medicine

Advantages

- ✔ Stem cells could be used to repair tissues.
- ✔ They could help to build entire organs for transplant.
- ✔ Your own stem cells would be a perfect genetic match.

Disadvantages

- ✘ The long-term effects of using stem cells are not yet known.
- ✘ There are ethical concerns surrounding the use of human embryos.
- ✘ There are many diseases that stem cells cannot treat.

Curing blindness

Could stem cells be used to restore sight?

The London Project to Cure Blindness is a collaboration between Moorfields Eye Hospital, University College London, the University of Sheffield, the British Government, and pharmaceutical company Pfizer. It aims to tackle a disease called 'wet age-related macular degeneration' (wet AMD), which causes rapid loss of central vision.

The team are using stem cells to grow sheets of retinal pigment epithelium (RPE) cells. These cells form a brown-coloured layer on the back of the eye that helps to absorb scattered light, aiding with vision, and help to nourish and protect the rods and cones that detect light entering the eye. The RPE cell layer can become damaged in wet AMD, so the team have used stem cells to grow a patch of new RPE cells to replace them.

The new cells behave just like the real thing in the lab, so in 2015, the first patient received the new treatment as part of a clinical trial. The initial results of the two hour operation will not be known until December 2015, and after that, a further nine patients will be tested to find out whether this pioneering treatment is safe, and crucially, whether it works. In the future, the team hope to be able to use stem cells to grow new rod and cone cells, repairing damage to the light-sensing machinery of the eye.

What is age-related macular degeneration?

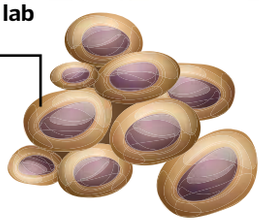
Age-related macular degeneration (AMD) is the leading cause of sight loss in adults the UK, affecting more than half a million people. The most common type is 'dry' AMD, caused by the breakdown of light-sensitive cells at the back of the eye, but people can also have more aggressive 'wet' AMD, caused by abnormal blood vessel formation. Both types lead to a loss of central vision.

AMD doesn't cause complete blindness, but affects the central vision, leaving only the edges intact

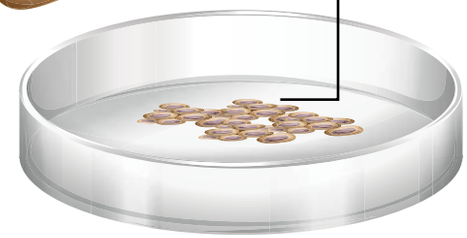
The treatment process

How stem cells can be transformed into specialised eye cells in the lab

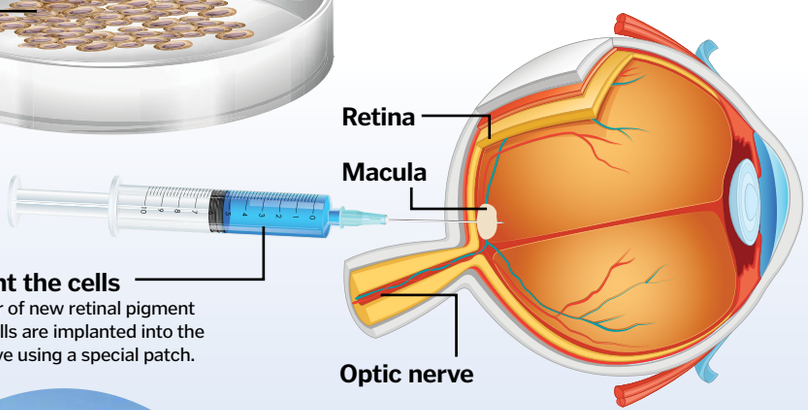
1 Collect stem cells
Stem cells are able to make copies of themselves indefinitely, and are capable of transforming into any cell in the human body, making them the perfect tool for repairing damaged tissues.



2 Add growth factors
The stem cells are given chemicals called growth factors, which encourage them to divide over and over to produce hundreds of identical clones.



3 Add differentiation factors
Researchers can control what type of cell the stem cells will become by using different combinations of chemicals. This process is known as differentiation.



4 Implant the cells
The layer of new retinal pigment epithelium cells are implanted into the back of the eye using a special patch.

5 After treatment
It is hoped that this treatment will help to restore some central vision to patients with age-related macular degeneration.

"The specialism that the stem cell chooses varies based on the signals it receives"

Defeating superbugs

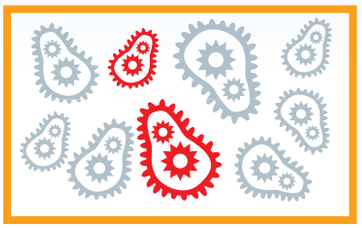
If we are going to survive future infections, we need to tackle antibiotic resistance

Just like humans, bacteria have variations in their genes that give them slightly different characteristics. This means that some bacteria will succumb to antibiotics faster than others. If the more hardy bacteria survive until the course of antibiotics has finished, they can then go on to create an entire colony with the same genetic advantages. The antibiotic you took before will no longer be effective in treating the infection. The more antibiotics are used, the more this cycle repeats, and there are now several strains of bacteria that are able to resist the effects of some of our most powerful drugs. Even more worryingly, antibiotic resistance genes can be passed from one bacterium to the next, and even between species.

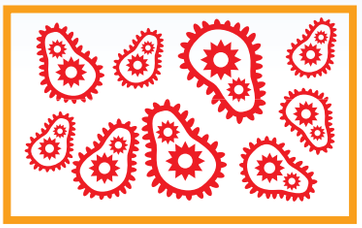
Antibiotic resistance

How do bacteria manage to survive high doses of our most powerful medications?

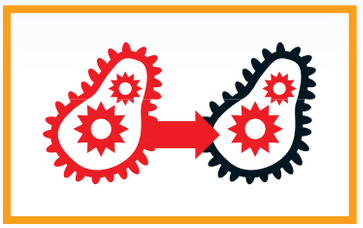
1 Different genes
Like us, individual bacteria from the same species can have slightly different genetic profiles.



2 Antibiotics
Antibiotics kill bacteria or stop them dividing, and they can affect both 'good' and 'bad' bacteria.



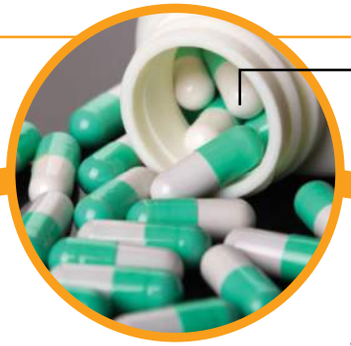
3 Some survivors
Some bacteria have genetic traits that help them to survive antibiotic treatment, so they can continue dividing.



4 Sharing genes
Resistant bacteria can sometimes pass their genes on to neighbouring bacteria, giving them resistance too.

How it spreads

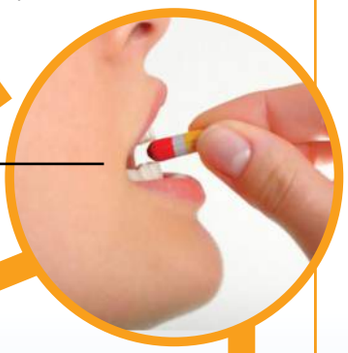
Overuse of antibiotics in people and animals is driving antibiotic resistance



Antibiotics
Every time antibiotics are used, bacteria have the chance to adapt.

Use in animals
Antibiotics are widely used to prevent and treat illness in domestic livestock.

Uncooked meat
Antibiotic resistant bacteria can turn up on meat, and can spread if not properly handled and cooked.



Use in people
Many people are prescribed antibiotics when they do not really need them.

Contaminated veg
Some antibiotic resistant bacteria may end up on the produce grown in the contaminated manure.

Infected fertiliser
Antibiotic resistant bacteria from animals can be found in their faeces, which is used as fertiliser for vegetables.

Infection in the community
In the community, antibiotic resistant bacteria can spread by direct contact or by contact with surfaces.

Hospital acquired infection
Antibiotic resistant bacteria can be transferred in hospital on unwashed hands, or on surfaces like door handles.

Teixobactin

The first new antibiotic discovered in 30 years!

In 2015, scientists unveiled Teixobactin – a new antibiotic that has the potential to combat fatal infections such as pneumonia and tuberculosis. This latest discovery was found in the same source of many other antibiotics – soil – where it is produced naturally by other bacteria. It marks a huge step in the bid to control drug-resistant strains of superbugs.

Teixobactin stops bacteria making the cell walls that they need to protect themselves

£10 million prize to solve antibiotic resistance

The 2014 Longitude Prize encourages both amateur and professional scientists to develop a test that can be used to help doctors choose the right antibiotic quickly and cheaply. Ensuring that we only take antibiotics when we need them, and that we are only given ones that will work on our specific infection, is crucial if we want to slow antibiotic resistance.

The Longitude Committee will judge entries every four months until the end of 2019

Personalised medicine

In the future, treatments will be designed for your unique genetic characteristics

The genetic differences that make us all unique also affect how we respond to medical treatment, and the genetic makeup of bacteria and viruses directly impacts their reaction to different drugs. Armed with an understanding of the genetics driving these different responses, we are moving toward a time when treatments could be personally matched to each patient. Steps are already being made with this kind of precision medicine in the treatment of cancer, where genetic differences in the tumour cells play a huge role in whether or not different treatments will work.

Matching medicines to genetics

People have different genes, so they respond differently to the same drugs

Patients awaiting treatment

These people all have the same cancer, but their genes are subtly different.

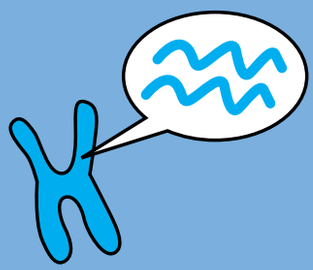
Normal drug clearance
Most patients can clear the drug quickly from their bodies.

Slower drug clearance
If the drug is cleared slowly, it can build up in the body, increasing side effects.

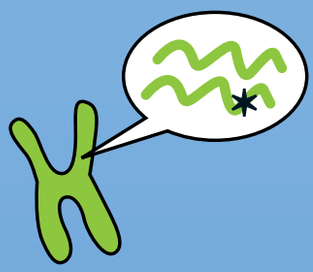
Poor drug clearance
A few patients clear the drug so slowly that normal doses become dangerous.

Different responses

Genetic differences affect how long it takes to clear the drug from the body.



Gene version one
A blood test identifies the patients as having the gene for normal clearance.

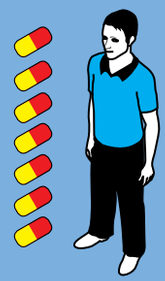


Gene version two
The blood test reveals a different gene, that gives a slower drug clearance.

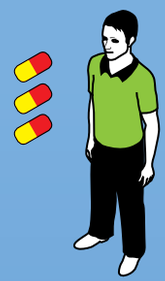
Gene version three
The gene identified in these patients means the drug will clear very slowly.

Tailored dosage

The patient can be given a dosage that matches their genetic makeup.



Normal dose
The patients that will clear the drug quickly are given a normal dose.



Medium dose
The patients that clear the drug more slowly are given a lower dose.

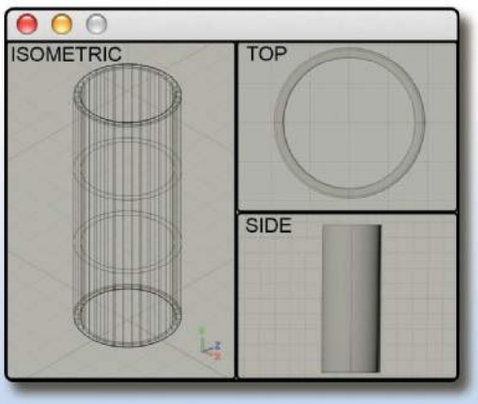
Low dose
The patients that struggle to clear the drug are given a small dose.

Printing body parts

The future holds custom-printed drugs and prosthetics, and even replacement body parts

Plastic 3D printers are a natural fit for creating prosthetics, but some of the most exciting medical 3D printers use a different kind of 'ink'. Using precision techniques, scientists are working on combining different medicines into one compact pill. Different ingredients could be included in the printer to control when each drug is released, and custom pills could be printed for each patient. This goal is still decades away, but printers could be used to make vitamin supplements much sooner.

3D printers can also be used to create custom surgical implants, from plates, to replacement joints, to scaffolds used to encourage cells to grow into new tissues. These printed structures can either be long-lasting or soluble. However, 3D printers don't just produce artificial body parts; they are also able to recreate the real thing. Some 3D printers are designed to print with living human cells, forming sheets of tissue that could be used as grafts to repair damage. Researchers at the Wake Forest Institute for Regenerative Medicine, North Carolina, are also working on printing cells directly on to the body to repair wounds. Printing entire organs is the ultimate goal, but whether it is actually possible is a topic of debate among scientists.



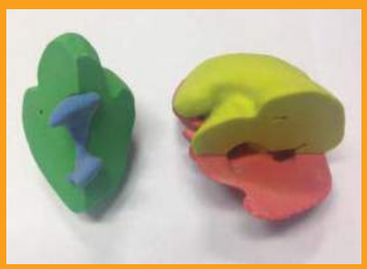
1 Computer control
The shape of the final printed structure is first mapped out on a computer, providing a template that can be used by the printer to construct the real thing.

Gel medium
The gel medium can be added separately, or mixed directly with the cells.

Bioink
The living cell mixture, known as 'bioink', is stored above the printer in a syringe.

3D medicine Printed medical supplies are on their way, and some are already available


3D printed drugs


Replacement organs

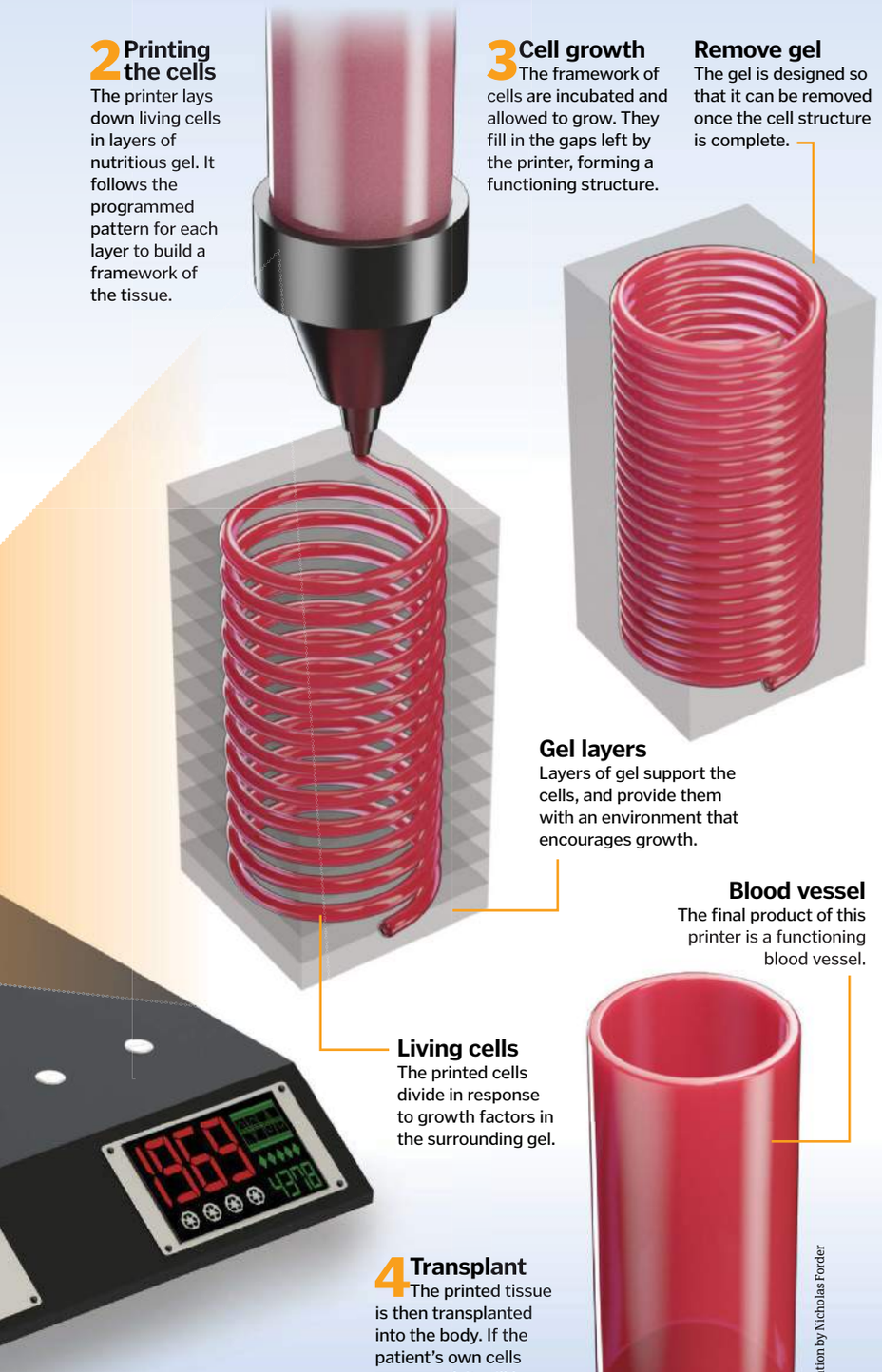

Prosthetics


Dentures

2 Printing the cells
The printer lays down living cells in layers of nutritious gel. It follows the programmed pattern for each layer to build a framework of the tissue.

3 Cell growth
The framework of cells are incubated and allowed to grow. They fill in the gaps left by the printer, forming a functioning structure.

Remove gel
The gel is designed so that it can be removed once the cell structure is complete.



Gel layers
Layers of gel support the cells, and provide them with an environment that encourages growth.

Blood vessel
The final product of this printer is a functioning blood vessel.

Living cells
The printed cells divide in response to growth factors in the surrounding gel.

4 Transplant
The printed tissue is then transplanted into the body. If the patient's own cells were used, it will be a perfect match.

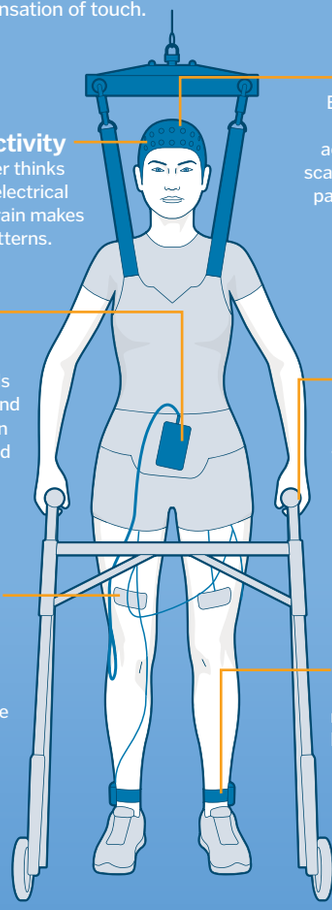
Illustration by Nicholas Forder

Helping people to walk again

The future of medicine is not just about biological advancements – robotics, prosthetics and complex electronics are set to play an increasingly important role in health care. Existing medical prosthetics are able to respond to nerve impulses or muscle movements in the body of the wearer, and now research teams are plugging medical aids into the brain.

Brain-to-tech interfaces read the electrical patterns of the brain. These can be recorded across the scalp using an electroencephalogram (EEG), and the patterns can be decoded by a sophisticated computer algorithm. A team at the University of California, Irvine, have developed a system that monitors signals from the brain, and transforms them into a series of electrical pulses. The pulses travel down wires attached to the muscles in the legs – effectively doing the job of the spinal cord.

The technology is still in development, but in early tests it enabled a man with a spinal cord injury to walk for the first time in seven years. Similar interfaces are also being trialled for use with prosthetics, and scientists are even working on sensors that can recreate the sensation of touch.



EEG
Electrodes record the electrical activity across the scalp, picking up the patterns generated by the brain.

Electrical activity
When the wearer thinks about walking, electrical activity in the brain makes recognisable patterns.

Processor
A computer programme interprets signals from the brain and creates a pattern of signals to send on to the legs.

Harness and frame
The harness and frame bear some of the weight of the wearer, and provide stability.

Electrodes
Electrodes attached to the knees deliver electrical impulses into the muscles that move the legs.

Gyroscopes
The position and movement of the legs is monitored by sensors on the ankles.

Skin grafts

Medical equipment

Splints, casts and braces

Bone implants

Vaccines of the future

The immune system fights infections much more efficiently if it has encountered them before

Most vaccines are made from a weakened or inactivated form of the pathogen, or even just some of its parts. These are injected into the body along with chemicals known as 'adjuvants', which help to get the immune system moving. The infection never takes hold, but as the immune system works to clear the vaccine, it develops highly targeted weaponry that can be used to fight the real thing.

These types of vaccinations have changed the world. Smallpox was eradicated in 1980 after a vaccination programme, and vaccines keep dozens of other infectious diseases at bay, but new techniques are being developed to take this protection even further. 'Recombinant viral vector' vaccines hijack viruses and use them as vehicles. Viruses inject their genetic information into cells, but using genetic engineering scientists can delete the genes that make them dangerous and replace them with something useful. Using this technique, harmless viruses are being created to carry training materials into the body to teach the immune system how to fight infections, or even non-infectious diseases like cancer.

A similar technique, known as DNA vaccination, directly injects genetic information into the muscle (usually attached to something like microscopic gold beads). These genes carry the instructions to make molecules found on infections, allowing the immune system a sneak peek before it has to encounter the real thing.

Painful needles could be replaced with harmless silicon patches in the future

Painless injections

The Vaxxas Nanopatch is one square centimetre (0.2 square inch) of silicone, coated in around 20,000 microscopic projections. These spikes are too small to see, but the end of each one is coated in vaccine.

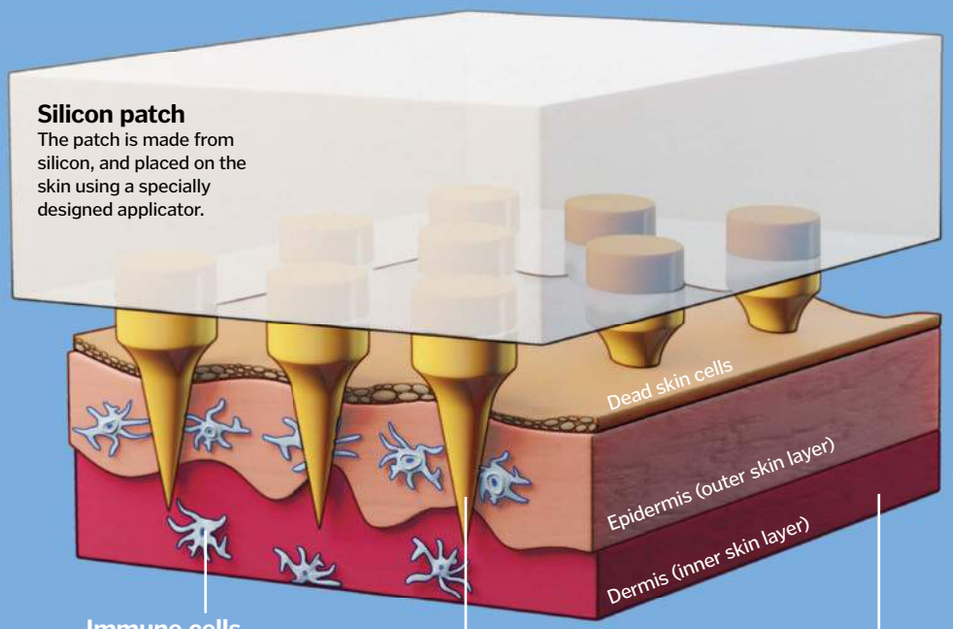


illustration by Nicholas Forder

Silicon patch
The patch is made from silicon, and placed on the skin using a specially designed applicator.

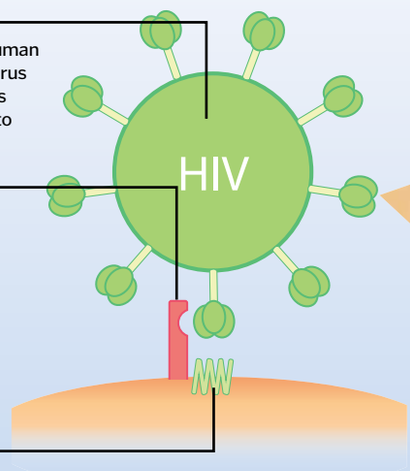
Immune cells
The vaccine is delivered straight to white blood cells beneath the skin, helping to kick-start the immune response.

Projections
Instead of one large needle, the patch uses thousands of microscopic projections.

Under the skin
The Nanopatch still penetrates the skin, but the microprojections cause much less disruption.

A vaccine for HIV?

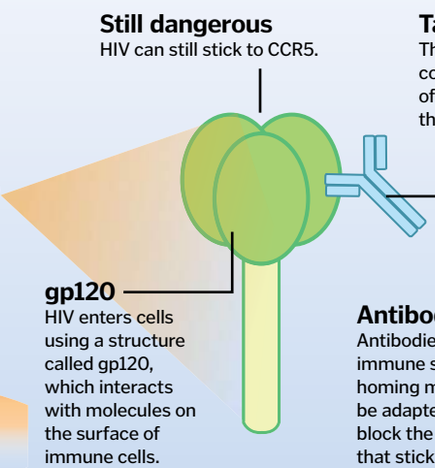
Scientists at the Scripps Research Institute in Florida are designing a vaccine that could help to prevent HIV infection. Their new treatment blocks the virus when it tries to stick to human cells, and has stopped HIV taking hold in animals



HIV
Like other viruses, Human Immunodeficiency Virus (HIV) needs to find its way into a living cell to reproduce.

CD4
HIV gets inside cells by holding on to a molecule called CD4.

CCR5
Holding on to CD4 allows HIV to stick to another molecule called CCR5, gaining entry into the cell.

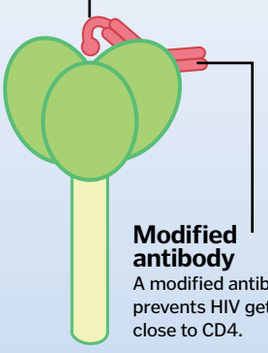


Still dangerous
HIV can still stick to CCR5.

gp120
HIV enters cells using a structure called gp120, which interacts with molecules on the surface of immune cells.

Antibody
Antibodies – the immune system's homing missiles – can be adapted in the lab to block the part of gp120 that sticks to CD4.

Tail
The long tail contains a fragment of CCR5, blocking the binding site.



Modified antibody
A modified antibody prevents HIV getting close to CD4.

A needle-free cure for Ebola

How a nasal spray could protect against one of the world's most deadly diseases

The current Ebola outbreak in West Africa has taken the lives of over 10,000 people so far, but finally a cure is on the horizon. For the past seven years, Dr Maria Croyle and her team at the University of Texas have been working on a vaccine that offers long-term protection against the deadly virus, and their latest tests show that it has a 100 per cent success rate in primates.

The vaccine, which is inhaled through the nose instead of injected, could enable fast control of future outbreaks and revolutionise the way life-saving drugs are produced. It's just one of the incredible discoveries explored in National Geographic's new series, *Breakthrough*. We spoke to Dr Croyle to find out more about her work and what the future holds for vaccines.

How did you develop the Ebola vaccine?
I was contacted by two scientists who were First Responders to many of the Ebola outbreaks and very interested in my project to develop a needle-free vaccine. I spent two months in their laboratory, where they had the genetic material for Ebola, and we developed the vaccine, which is essentially a cold virus called the adenovirus.

We took out the DNA from the cold virus that allowed it to replicate and make us sick, and replaced it with the sequence of the protein that covers the outside of the Ebola virus. We figured if we could get an immune response against that protein, the virus is pretty much dead in the water and can't make someone sick.

Why does it take so long to develop a vaccine?
It's great to rush something out to the people that need it, but if there is any chance that it may not be safe, that could completely destroy a vaccine that may otherwise be very good. So that's why there is something called the 'three animal rule'. Essentially you have to test the vaccine in three animal models that reflect the human disease. Throughout the whole process, not only did we look for the fact that there's a good immune response, we also looked for toxicities that could cause a problem.

What are the most important benefits of a needle-free vaccine?
A lot of places affected by the Ebola outbreak are very isolated villages where they are not used to people that aren't part of their culture. It isn't acceptable for someone outside of that to go after them with a needle. Plus, the nasal spray alerts the immune system to the areas where one would be exposed to Ebola – through cuts or abrasions in the skin – much faster than an injection does.

What stage is the vaccine at right now?
It's ready to go. We're currently in the process of talking with two major companies that have the resources to produce it on a large scale and can really help to get it to the people who need it most. We really hope within the next year it will be available.

How do you think the process of producing vaccines will change in the future?
The way we stabilise the vaccine is unique and we think it will change the way certain vaccines that need refrigeration are produced. In our studies with mice and guinea pigs, we found that if we placed the vaccine under the tongue, it seemed to work really well. So we stabilised the vaccine in this thin, flexible film that almost looks like a fruit rollup. This way, we found that we could store it at room temperature for at least three years. We could then simply put it in an envelope, ship it to where it was needed and once it got there, add water to the sheet of vaccine and in minutes it could be used as a nasal spray.

The needle-free Ebola vaccine is inhaled through the nose instead of injected

Breakthrough is the ground-breaking series about some of the world's leading scientists and how their cutting-edge innovations and advancements will change our lives in the immediate future and beyond. It is currently airing on Sundays at 10pm on the National Geographic Channel.

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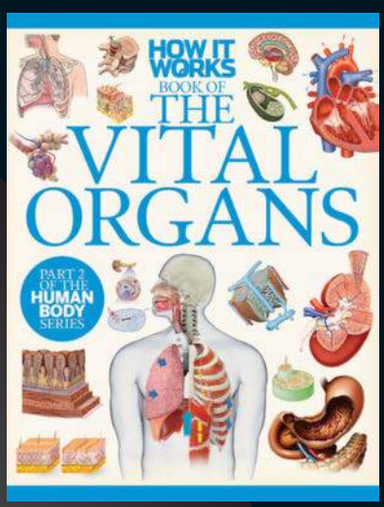

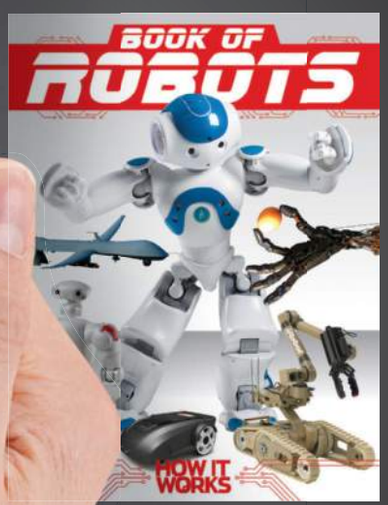

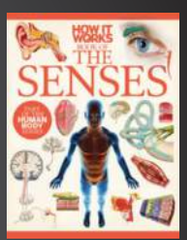

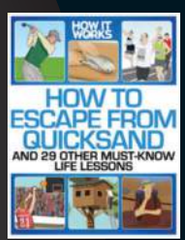

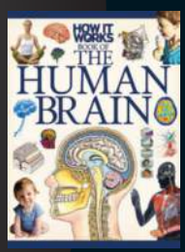

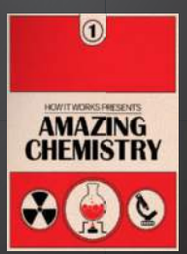

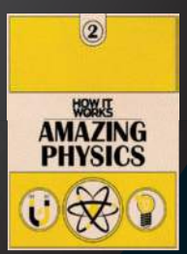

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How does convection work?

Discover how soup, your house and even planet Earth are heated

Convection is the process that transfers heat through liquids and gases, which are collectively known as fluids. It's happening all around you, and is easy to see in action right in your own home. When a shaft of sunlight shines through the window, you should be able to see dust particles swirling in the air. These are being carried by convection currents, rising upwards with warm air and falling again as the air cools. This process is what heats your home and warms your soup on the stove, but it also happens on a much larger scale too. For example, convection currents in the Earth's atmosphere cause warm air to rise through the colder air above it. As it does so, moisture in the air condenses into water droplets that form the clouds responsible for thunder, lightning and rain. In the Earth's mantle, convection currents move the tectonic plates, forming volcanoes and causing earthquakes as they pull apart and collide. However, perhaps the grandest, and most important, example of convection can be found in the Sun, as currents transfer heat energy from its interior to its surface, allowing it to eventually reach Earth.

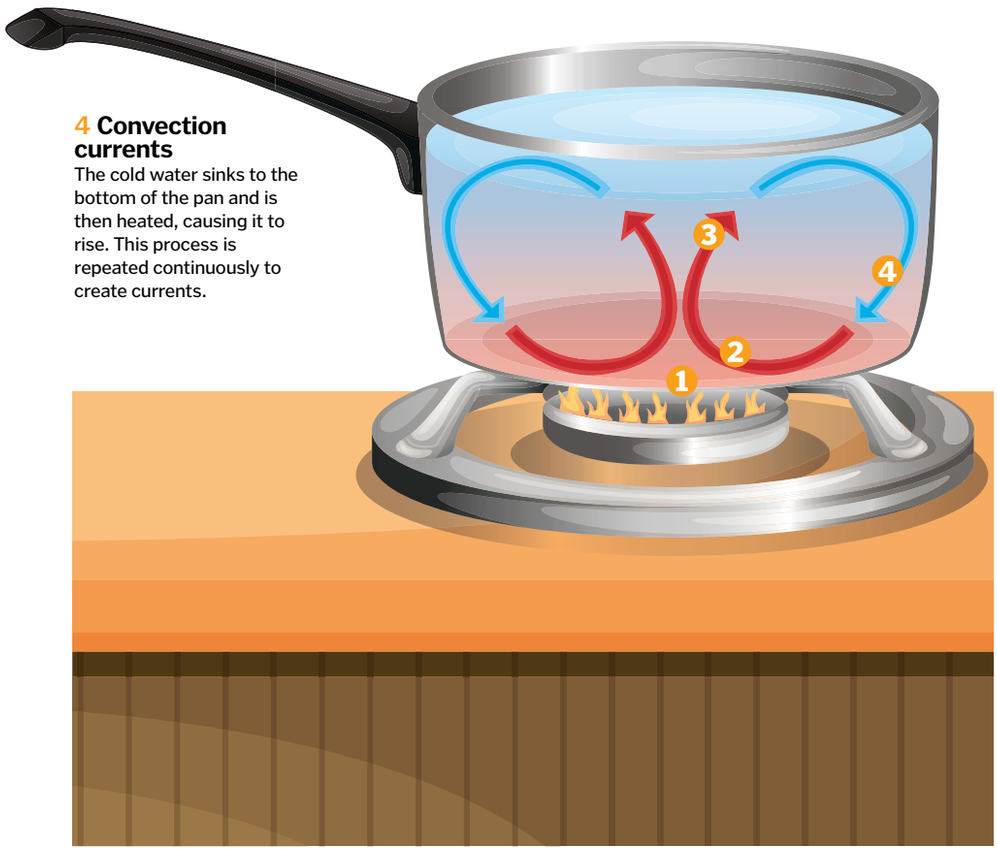
Saucepan science

Discover how your water heats up on the stove

1 Conduction
Heat energy is transferred from the stove, through the pan and to the water by conduction.

2 Heating up
As the water molecules heat up, they move further apart and as a result, take up more volume.

3 Hot water rises
The greater volume of the hot water decreases its density, causing it to rise above the denser, cold water.



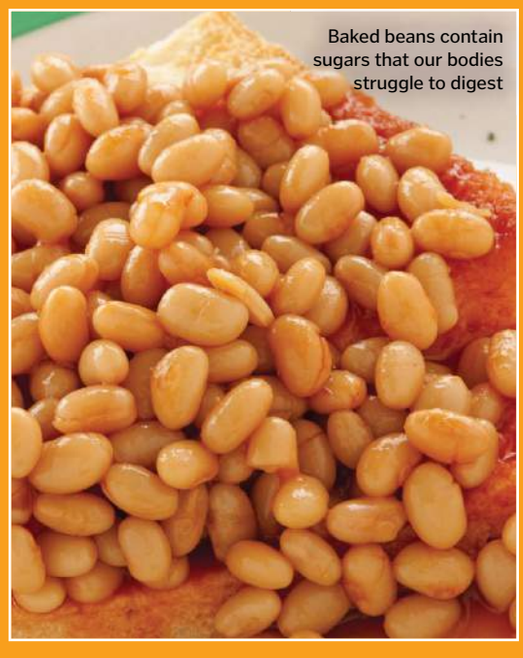
4 Convection currents
The cold water sinks to the bottom of the pan and is then heated, causing it to rise. This process is repeated continuously to create currents.

Why do baked beans give you wind?

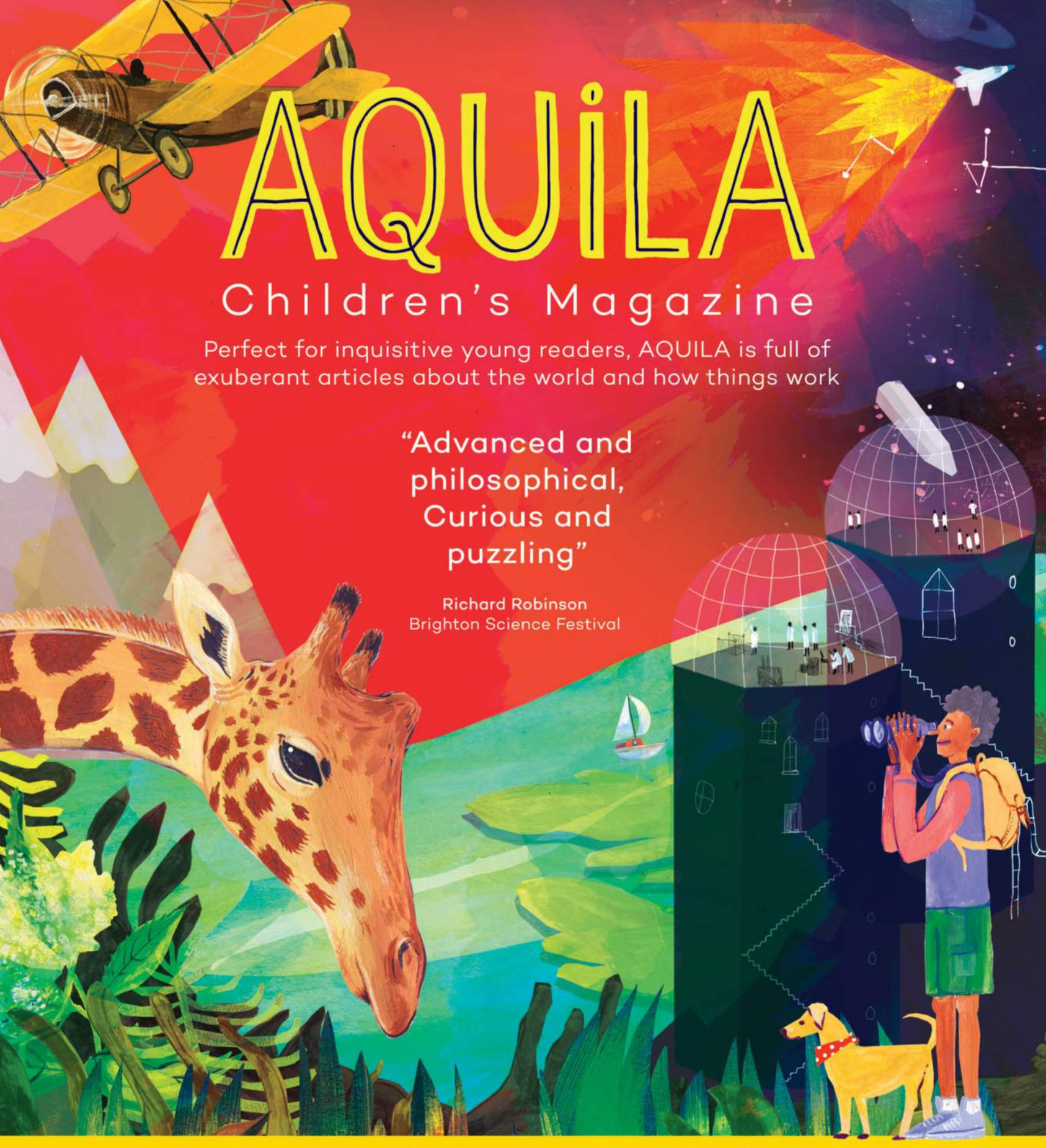
You can blame it on the bacteria in your gut

Baked beans are a tasty treat that are high in fibre and therefore good for your digestive system. However, as they make their way through your body, they also produce an unfortunate side effect: flatulence. This bodily function is a result of sugars called oligosaccharides that are contained within the beans. These sugar molecules are too big to be absorbed in our small intestines, and our bodies do not produce the enzyme that can break them down, so they carry on through to the large intestines intact and undigested. Here, they're met by our gut bacteria, which have no problem breaking them down into something more manageable. As they do this, they produce gasses including hydrogen and methane, which gradually accumulate in your lower intestine and escape through your rectum as flatulence.

However, if you want to avoid having to blame the noise (and smell) on the dog, then there are some gas-relieving supplements that you can take. These typically contain the enzyme alpha-galactosidase, which is capable of breaking down the sugars in the small intestine, before those pesky gas-producing bacteria can get to them.



Baked beans contain sugars that our bodies struggle to digest



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The physics of archery

What really happens when you pull back the drawstring, take aim and fire?

Made famous by the likes of Robin Hood and more recently Katniss Everdeen, archery is both a worldwide sport and an ancient hunting technique, developed during the late Stone Age. Whether it's a traditional long bow or a more modern recurve bow, the physics behind firing an arrow is much the same.

The bow essentially acts as a two-armed spring. As the arrow is pulled back on the drawstring, the bow works to convert the force into potential energy. The force applied by the archer, known as the draw weight, bends the bow's limbs and adds elastic potential energy, ready to transfer to the arrow when the drawstring is released. Hooke's Law states that the draw weight is proportional to how much you deform the bow's limbs (how far you draw the string back), something known as the draw length.

When archers become more experienced, they are able to draw their arrow to an identical point (usually in line with their cheek, temple or ear) each time. This helps them to fire every arrow at the same speed, which improves their accuracy and ensures that they consistently hit the target.

Shooting an arrow

With science and practice, archers can consistently hit the target

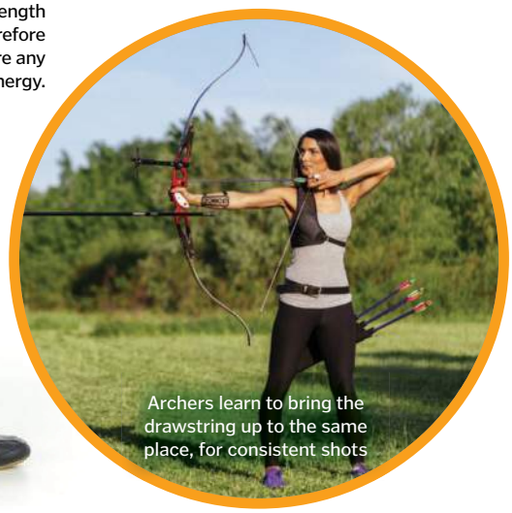
Energy transfer
As soon as the string is released, the stored energy from the bow is transferred to the arrow, sending it soaring.

Drag
When the arrow is released it creates drag by pushing on the air, which pushes back and slightly alters its flight path.

Potential energy
When the drawstring is pulled back, the bow is bent, causing it to store potential energy.

Gravity
This force will be pulling the arrow down towards the ground, so archers must aim higher to compensate for this.

Drawstring
The drawstring doesn't change length when pulled, therefore doesn't store any potential energy.



Archers learn to bring the drawstring up to the same place, for consistent shots

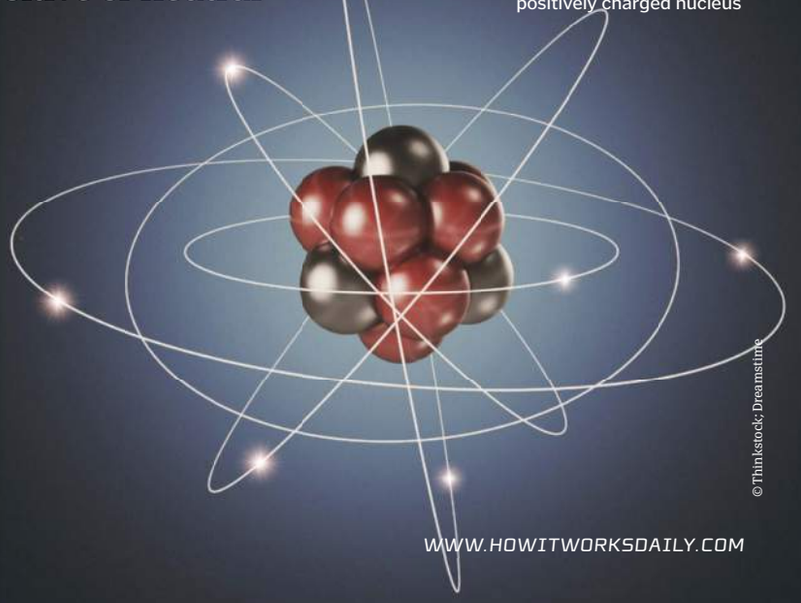
What is an electrical charge?

Find out why some objects can be negative, positive or neutral

Everything you see around you is made of matter, which is composed of tiny particles called atoms. The centre of the atom – known as the nucleus – is a bundle of chargeless neutrons and positively charged protons, and is surrounded by negatively charged electrons.

If an atom contains an equal number of protons and electrons, their opposing charges will be balanced and the atom will be electrically neutral. However, if there are more electrons than protons, the atom will be negatively charged; likewise if the atom has more protons than electrons, then it is positively charged. Since everything is made up of these atoms, the same principle applies on a larger scale; objects with an excess of electrons will be negatively charged and vice versa.

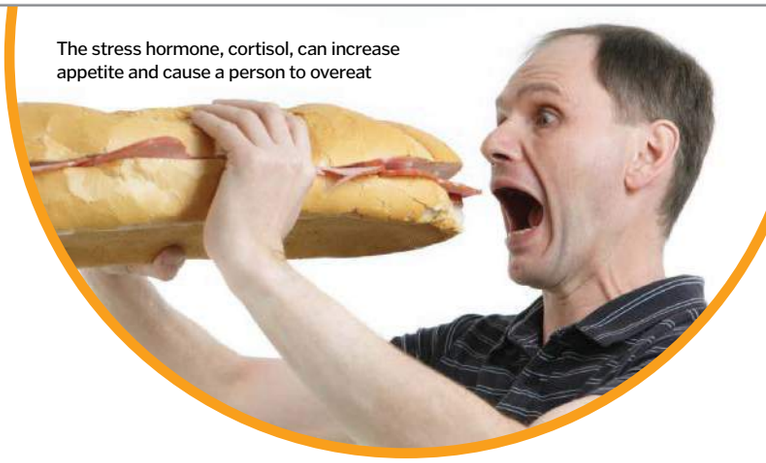
Charge is measured in Coulombs and, much like energy, it cannot be created or destroyed; it can only be transferred. Scientist Benjamin Franklin devised this theory in 1747, stating that the net quantity of electric charge in the universe is always constant.



The Rutherford model is a simplified representation of atomic structure, showing negative electrons orbiting the positively charged nucleus

The biology of hunger

Grab a snack, and then find out what's really going on in your rumbling tummy



The stress hormone, cortisol, can increase appetite and cause a person to overeat

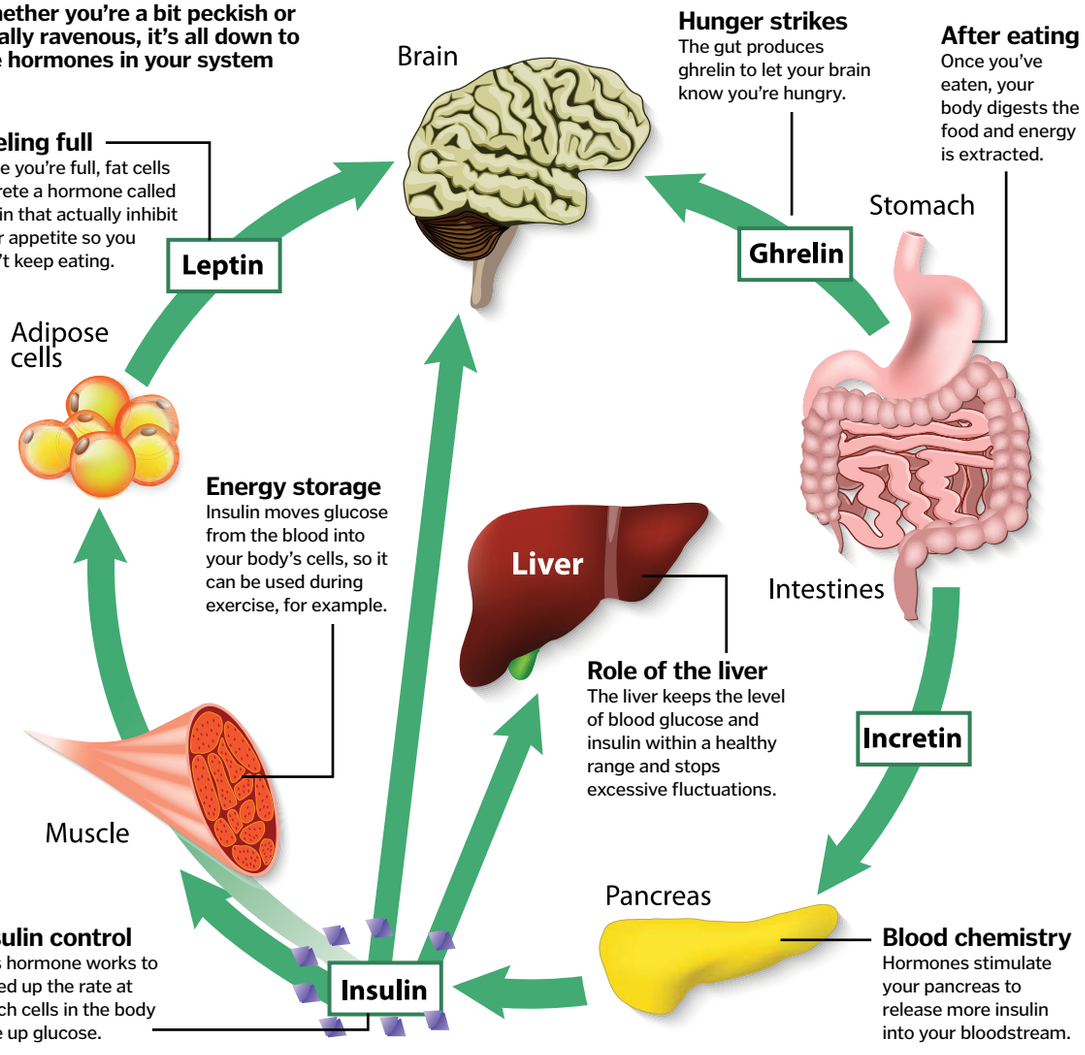
The feeling is all too familiar: a growling in the pit of your stomach that usually starts around late morning when breakfast is just a memory and lunchtime is still a tiny speck on the horizon. It's hunger – a feeling that begins with the hormone known as ghrelin. Once your body has finished digesting and using up the energy from your last meal, your blood sugar and insulin levels drop. In response to this, ghrelin is produced in the gut and travels to the brain, letting it know that sustenance is needed. The brain then commands the release of a second hormone called neuropeptide Y, which stimulates appetite.

Once you have answered the call and filled up on a good meal, your stomach gets to work on digestion. Nerves in your stomach sense stretching that lets your brain know you're full up. Three other hormones also secreted by your digestive system take messages to the brain: cholecystokinin (CCK), GLP-1 and PYY. CCK helps to improve digestion by slowing down the rate at which food is emptied from the stomach into the small intestine, as well as stimulating the production of molecules that help to break down food. GLP-1 tells the pancreas to release more insulin and also reduces appetite. The hormone PYY is secreted into the bloodstream by the small intestine after eating. It binds to receptors in the brain to make you feel full up.

Once all of the food is digested, the blood sugar and insulin levels drop and ghrelin is produced once more, so the hunger cycle continues.

Hungry hormones

Whether you're a bit peckish or totally ravenous, it's all down to the hormones in your system



When the mind takes over...

When our bodies tell us we are hungry, it's an innate reaction – the hormones in our systems let us know of the need for sustenance. But when our minds get involved, it's a whole different story.

There's not much nutritional value in a bacon sandwich or a frosted cronut, for example, so it's not a 'need' for a treat, it's a 'want'. This is because the very first time you experienced a cronut, the mesolimbic centre of your brain (the region that processes pleasure) lit up, as the fatty, sugary goodness of the treat released chemicals known as opioids that bind with receptors in the brain.

This triggers the release of dopamine, the feel-good hormone that makes us happy. It's actually the same one that is released when we fall in love! Your brain remembers this response, and is encouraging you to munch on that delicious cronut to repeat the pleasurable feeling.

It's the reward circuit in your brain that creates the urge for sweat treats!

60 SECOND SCIENCE

The general theory of relativity

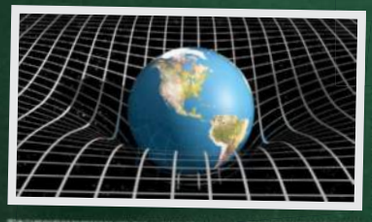
GET TO GRIPS WITH EINSTEIN'S THEORY OF THE UNIVERSE

BACKGROUND

In 1905, Albert Einstein published his theory of special relativity, explaining that the speed of light in a vacuum is constant and so are the laws of physics when they are observed while not accelerating. He proved that everything moves relative to everything else, but it only applied to special cases; it did not apply to observers who were speeding up or slowing down. Einstein set about extending his theory so that it could apply to everything in the universe, forming a theory of general relativity.

IN BRIEF

According to Isaac Newton's first law of motion, objects do not accelerate unless an external force acts upon them. However, Einstein realised that when you are in freefall, you feel weightless, so you feel no force even though you're accelerating towards the ground. He determined that what we experience as gravity must be the result of massive objects curving space-time itself. Any objects moving through this warped space-time follow as short a path as possible, which is a curve. This helped to prove that Earth's orbit was not determined by gravity pulling it towards the Sun, as had been previously thought, but was rather the result of curved space-time forcing our planet along the shortest possible route around its host star.

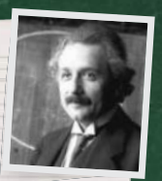


SUMMARY

The theory of general relativity proves that gravity is caused by the curvature of space-time and does not pull objects, but instead forces them along the shortest possible path.

Albert Einstein

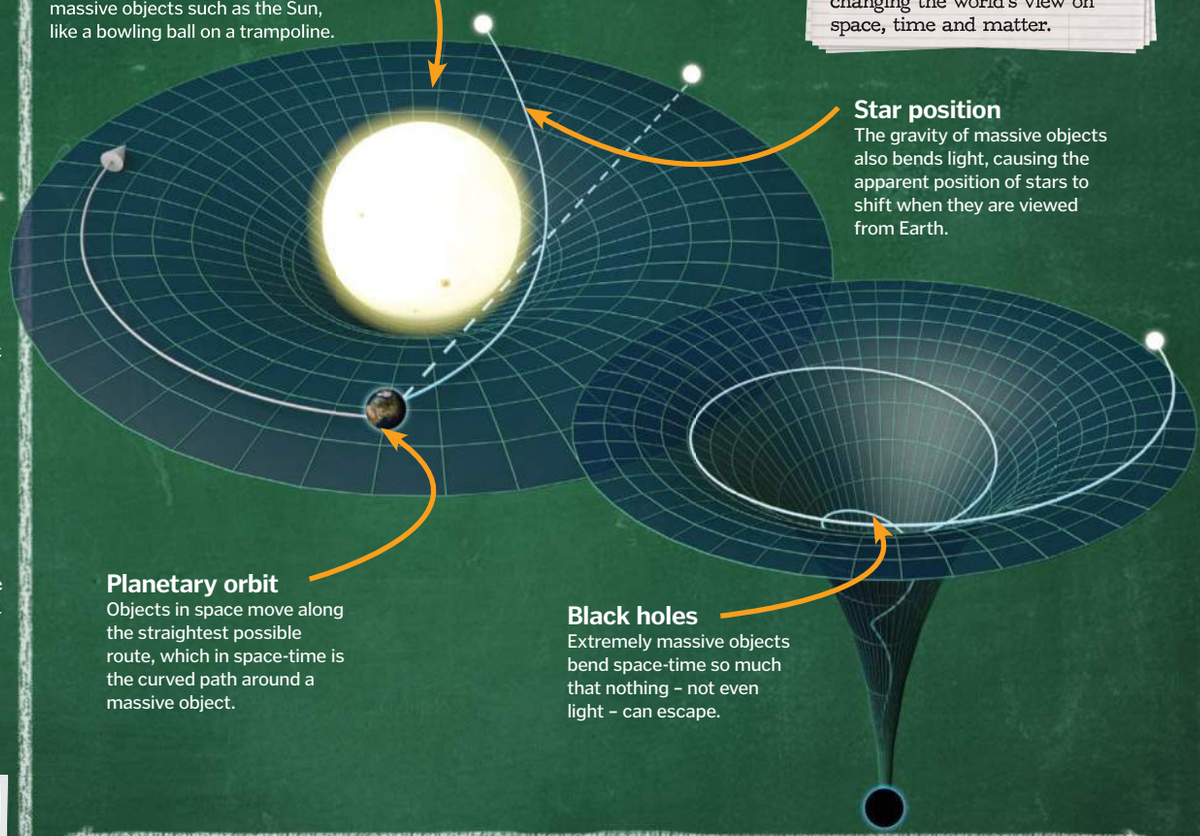
1879-1955



Einstein considered his general theory to be the culmination of his life's research. After it was published in 1915, he became world famous almost overnight and in 1921, was awarded the Nobel Prize for Physics. He published more than 300 scientific papers in his lifetime, changing the world's view on space, time and matter.

Bending space-time

Explaining motion and the path of light in space



HOW GENERAL RELATIVITY CHANGED THE WORLD

- EINSTEIN HAD SOLVED THE MYSTERY OF WHERE GRAVITY COMES FROM – THE CURVING OF SPACE-TIME.
- IT WAS DISCOVERED THAT THE CURVATURE OF SPACE-TIME AROUND EXTREMELY DENSE OBJECTS IS INFINITE, FORMING A HOLE IN THE FABRIC OF SPACE-TIME, KNOWN AS A BLACK HOLE.
- USING GENERAL RELATIVITY, EINSTEIN PROVED THAT GRAVITY BENDS THE PATH OF LIGHT AND GIVES STARS A FALSE POSITION IN THE SKY WHEN SEEN FROM EARTH.
- THE EQUATIONS OF GENERAL RELATIVITY HELPED REVEAL THAT THE UNIVERSE IS EXPANDING, LEADING TO THE DEVELOPMENT OF THE BIG BANG THEORY.

The Tech Behind Treasure Hunters

Discover the incredible tech Indiana Jones wishes he had

When we think of an archaeologist, most of us picture a dusty, khaki-clad outdoorsy type, waist deep in a pit in Egypt and clutching a shovel and hand brush – but times have changed. While those tools are certainly still in use on excavation sites, modern archaeologists' toolkits bristle with new technologies that allow them to probe deeper, dig smarter and preserve better.

At the most basic level, advances in robotics have made researchers safer while studying cramped, hostile places. In dangerous locations, the option to send in a robot to scout out the situation is invaluable. Getting an advanced look at sites before the shovel-wielding ground crew descends also helps them target their efforts and limit collateral damage during the dig.

High-tech ways to visualise the seen and unseen elements of a site – like ground-penetrating radar and magnetometry – deliver more powerful and persuasive data. Compared to the old staples of painstaking field notes, drawing and photo documentation, researchers can learn more in less time, and cause fewer disturbances while doing so.

"There are many, many mini revolutions going on in technology and archaeology at the moment," explains Dr Henry Chapman, Senior Lecturer in Archaeology and Visualisation at the University of Birmingham.

"For some time there's been a mismatch between the ability to capture high-resolution data and the ability to actually process it." But with the computing power available today, he says, "Rather than just look at one data set and understand that, we can start combining data sets. We call it data fusion."

The proliferation of technology means that amateurs can get in on the act too. In September, two men in Poland claimed to have discovered the fabled Nazi gold train. According to hearsay, the train was driven deep into a maze of subterranean mountain tunnels as the Soviet Army marched on East Germany in the final days of World War II. It is rumoured to contain up to 300 tons of gold, jewels and valuable artwork. The men say they discovered it using ground-penetrating radar, following a tip-off from a dying man.

Technology can also be used to preserve precious sites. Imaging in 3D gives researchers a novel way to look back in time, producing accurate site renderings they can return to again and again, even after the sites have been altered by excavation.

Chavín de Huántar

Inside the 3,000-year-old temple of an ancient mind-controlling cult

Underground labyrinth
A 3.2-kilometre (two-mile) network of interconnected passages ran beneath the old and new temples in pitch black, aired only with tiny holes.

New temple
Built adjacent to and on top of the old temple over the course of several generations, the new temple expanded the site significantly.

Tello Obelisk
A rectangular pillar carved with images of caimans, snakes, jaguars and plants stood in the centre of the plaza.

Perimeter ornamentation
Anthropomorphic stone heads with both feline and human features depicted the characteristic streaming-mucus effect of hallucinogenic plants.

Circular plaza
The heart of the complex was a sunken ceremonial circle where hypnotic open-air rituals involved hundreds or thousands of participants.

The real-life Temple Of Doom

Somewhere on the high plains of the Peruvian Andes, an ancient relic dubbed 'the real-life Temple of Doom' lies in ruin. The 3,000-year-old Chavín de Huántar temple was once the ceremonial nexus of the Chavín civilisation; a place where followers flocked to take part in psychedelic mass rituals.

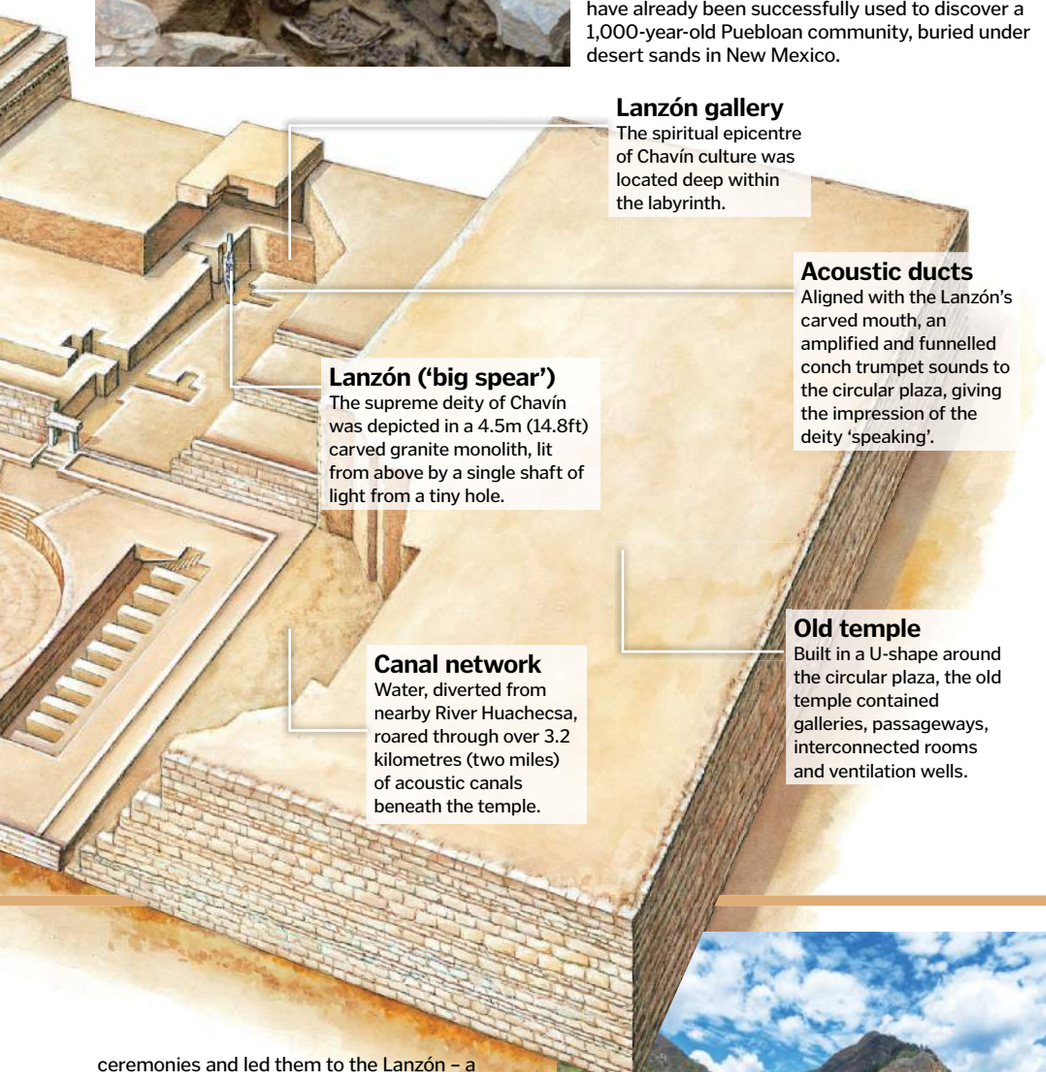
The elaborate ceremonies involved music, dance, and mind-altering plants. Carvings around the temple depict strange half-human, half-animal beings, while the outer walls are adorned with anthropomorphic stone heads whose noses stream with mucus – a common side effect of taking the powerful hallucinogens. But that's just the beginning.

Beneath the main temple, archaeologists discovered a labyrinth of dark passages. They believe that priests would have taken a chosen few cult initiates into these tunnels during the

Drones before digging

Since the 1970s, archaeologists have exploited the heat-storing properties of stone to identify buried structures using thermal imaging cameras. That's because, in ground warmed over the course of a day, stone retains heat differently compared to the surrounding soil, and in the cool of the night infrared cameras can easily pick it out from the background.

However, getting a thermal camera in a position to take those pictures – on board planes, kites or balloons – has proved time consuming, expensive and occasionally dangerous. Enter drones. These flying robots, which have a battery life of around 15 minutes, have already been successfully used to discover a 1,000-year-old Puebloan community, buried under desert sands in New Mexico.



Lanzón gallery
The spiritual epicentre of Chavín culture was located deep within the labyrinth.

Acoustic ducts
Aligned with the Lanzón's carved mouth, an amplified and funnelled conch trumpet sounds to the circular plaza, giving the impression of the deity 'speaking'.

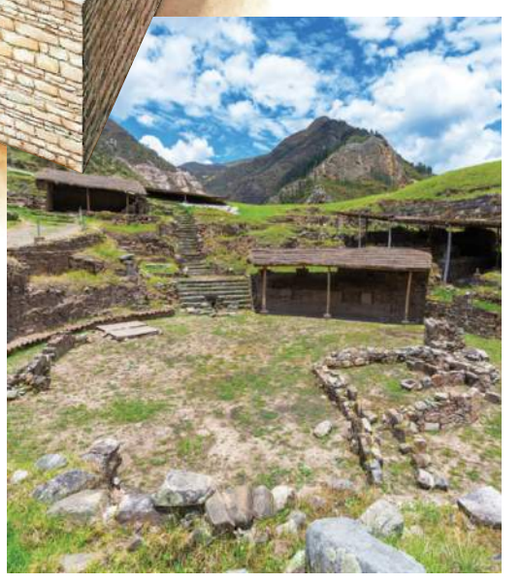
Lanzón ('big spear')
The supreme deity of Chavín was depicted in a 4.5m (14.8ft) carved granite monolith, lit from above by a single shaft of light from a tiny hole.

Old temple
Built in a U-shape around the circular plaza, the old temple contained galleries, passageways, interconnected rooms and ventilation wells.

Canal network
Water, diverted from nearby River Huachecsa, roared through over 3.2 kilometres (two miles) of acoustic canals beneath the temple.

ceremonies and led them to the Lanzón – a towering granite monolith carved with a snarling, panther-like face; the supreme deity of Chavín. A single shaft of light would have illuminated the Lanzón, and a roaring sound – caused by water rushing through a network of underground canals – would have reverberated around the walls. The overall effect must have been a psychedelic blur of terror and transcendence.

Over the last decade, technology has provided fascinating new insights into just how organised the Chavín culture was. In 2007, 3D scans of the temple revealed that the placement of staircases was consistent, suggesting the Chavín had a building code. More recently, a high-tech acoustic analysis of the labyrinthine spaces showed that they are architecturally optimised to filter and transmit sounds made by the ceremonial conch shell trumpets discovered at the site in 2001.



3D scanning in archaeology

When archaeologists leave excavation sites, they typically have to leave the most important pieces of the puzzle – the artefacts they find there – behind. Most countries strictly prohibit researchers from removing these precious pieces of history, so they must rely on their field notes and photographs for further analysis.

However, as handheld 3D scanning technology becomes cheaper, the scientists have another option. Making 3D scans of objects in the field not only allows them to collect more detailed data for their own use; it also enables them to transmit the images to collaborators around the world, who can consult on the field work as it happens.

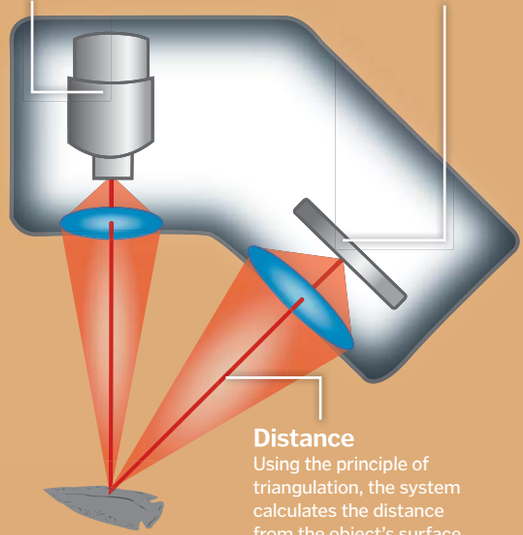
The richness of this sort of 3D data enables researchers to compare artefacts using computer software, and study ideas as diverse as locomotion, function and cultural identity. Scan data can also be used in conjunction with 3D printing to allow students and scholars to physically handle and connect with artefact copies, without worrying about damaging the original.

How it works

3D scanners make accurate virtual renderings of objects without physically touching them

Laser source
A laser beam is shone on to the surface of the object.

Camera
Light reflected back towards the scanner is picked up by a camera, which registers its precise angle and intensity.



Distance
Using the principle of triangulation, the system calculates the distance from the object's surface to the camera.

Superposition
Reference points are used to overlay images taken from multiple points of view and render the object in 3D.

Remote sensing

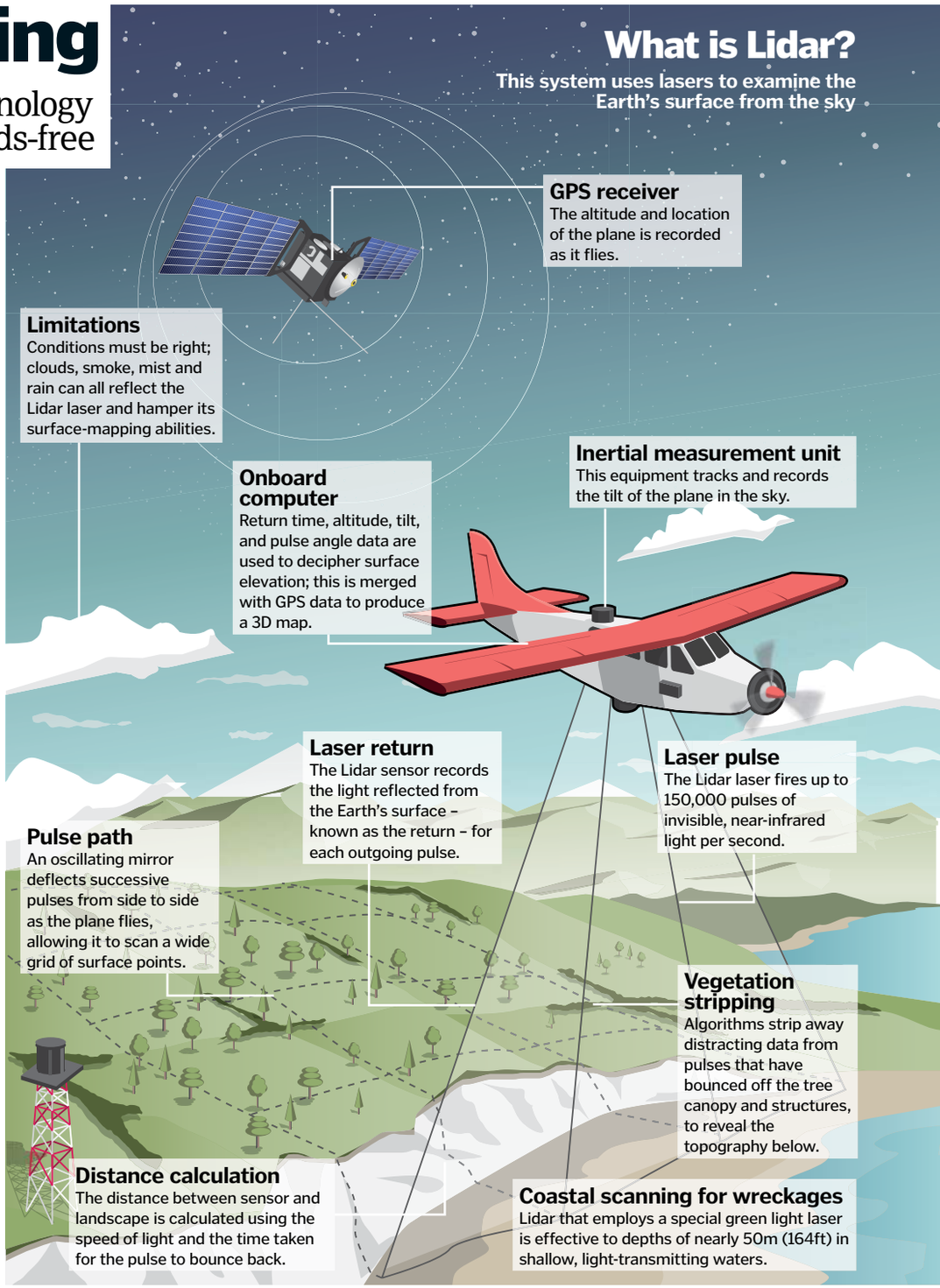
How non-invasive sensing technology has helped archaeology go hands-free

Uncovering the past is time-consuming, expensive and labour-intensive. Field campaigns take months or years to plan and their execution is necessarily slow, cautious and focussed on preserving as much as possible. By using cutting-edge remote sensing techniques, archaeologists can postpone and even avoid turning to their shovels, and sometimes learn more about the site in the process.

Aerial photography has been a mainstay of archaeology since the 1950s, but its application is limited to exposed areas of ground. Today, Lidar (short for Light Detection and Ranging) – which uses lasers to map the ground that's hidden by vegetation – makes it possible to study the surface characteristics of forested regions too.

Similarly, ground-penetrating radar uses the echoes of harmless sound waves to locate underground structures. Magnetometry and resistivity measurements identify buried materials based on how they interact with magnetic fields and electric currents, respectively. Combining these techniques and others, researchers can build up richly textured 3D maps of what lies beneath, without a speck of earth being disturbed. Remote sensing techniques aren't only about preservation; some provide sight beyond sight. Ray guns, for example, uncover what an object is made from by analysing the way its atoms fluoresce in an X-ray beam.

In the burgeoning field of space archaeology, remote sensing instruments on Earth-orbiting satellites take pictures of the Earth in a range of electromagnetic bandwidths. Each bandwidth can tell us something different about the surface, with some revelations being quite profound. Infrared imaging, for example, can pick out chemical changes in soils that were caused by the building practices and activities of ancient cultures. Not bad for an eye in the sky thousands of kilometres away!



How tech discovered 'super-henge'

Stonehenge – an ancient circle of gigantic standing stones in Wiltshire, England – is one of the wonders of the world and the best-known prehistoric monument in Europe. The enigmatic stones have enthralled archaeologists, historians and mystics for centuries, but in the last five years things have become especially interesting.

An unprecedented initiative that used non-invasive geophysical surveying techniques revealed a bombshell: the iconic henge is surrounded by another 17 buried Neolithic monuments, including a colossal 'super-henge' – an arc of 90 massive stones, covering almost 1.6 kilometres (one mile) in length. The Stonehenge Hidden Landscapes Project created an underground map of the area using a suite of sensors, mounted on trailers and then pulled around the site by quad bikes and tractors.

The kit included ground-penetrating radar and magnetometers that detected local variations within the Earth's magnetic field caused by buried stones. Special software integrated GPS data with the sensor data as it was recorded, and together the readings reveal the remains of human activity from 11,000 years ago.

A motorised magnetometer system records magnetic anomalies in the ground near Stonehenge

The Curasub can carry sampling arrays and up to five people to depths of 300m (980ft)

The EXOSUIT maintains surface pressure, allowing divers to return to the surface quickly

Exploring shipwrecks

Revolutionary new tech helps archaeologists fathom some of the ocean's greatest mysteries

The ocean floor is littered with shipwrecks and treasure, but underwater exploration is a perilous pursuit. Diving is fraught with risks like nitrogen narcosis, decompression sickness (also known as the bends) and malfunctioning gear, not to mention the dangers posed by collapsing ship structures, hostile sea life and sudden storms or currents. Even experienced divers can get lost or become trapped in wrecks, and many lie too deep for divers to venture into.

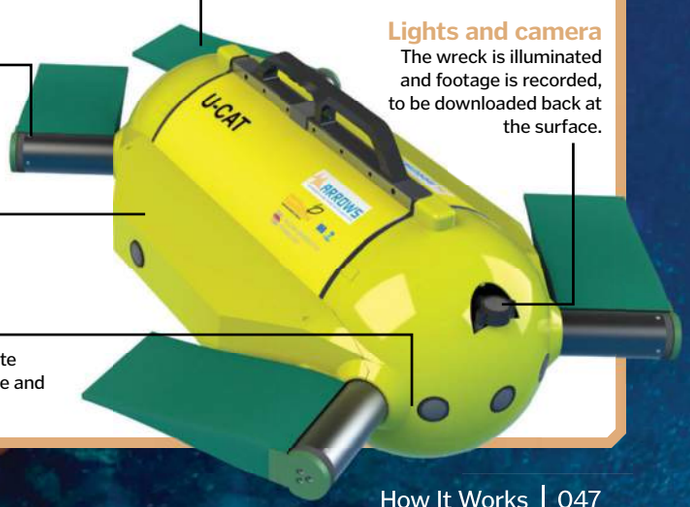
To tackle these problems, underwater archaeologists are turning to manned submarines, remotely operated robots, underwater drones and revolutionary new diving gear. In 2014, the Return to Antikythera project set out to revisit a 2,000-year-old wreck that rests on the bottom of the Aegean Sea. Sponge divers first discovered it in 1900, 60 metres (200 feet) under, off the coast of the Greek island of Antikythera. These first explorers retrieved a bounty of jewels, marble sculptures, and 'the world's oldest computer' – a priceless clock-like astronomy mechanism. However, their explorations left one diver dead and two paralysed.

The Return to Antikythera team used side-scan sonar and data from an autonomous underwater vehicle, mounted with stereo cameras, to build a high-resolution 3D map of the ocean floor in advance. They used this to pinpoint where to send divers, who were kitted out with re-breathers that scrubbed carbon dioxide from their exhaled air and recirculated it. This freed the divers from carrying so many oxygen tanks, while at the same time giving extended time underwater – up to three hours.

To go deeper and longer underwater, divers wore an EXOSUIT – a metal shell that lets the wearer operate at depths of 300 metres (980 feet). A foot pedal is used to control thrusters, and a high level of dexterity is retained due to the suit's articulated joints. It also maintains surface pressure, allowing the wearer to return swiftly to the surface in an emergency without getting decompression sickness.

U-CAT robot turtle

Designed to explore sunken ships autonomously, the U-CAT is underwater archaeologists' newest and cutest little helper



Flippers
The flippers don't disturb surrounding water or kick up silt like propellers would, helping U-CAT to capture clear video footage.

Lights and camera
The wreck is illuminated and footage is recorded, to be downloaded back at the surface.

Highly manoeuvrable
Using four independently driven flippers, the U-CAT can move forwards, backwards, and turn gracefully on a point.

Cable-free
Completely un-tethered and with a battery life of four hours, the U-CAT can explore unhindered.

Semi-autonomous
The robot attempts to follow a pre-defined route using navigation sensors; it uses sonar to locate and avoid obstacles and unexpected roadblocks.

The hidden doorways of Tutankhamun's tomb

Scans suggest Egypt's lost Queen Nefertiti may lie within a concealed chamber

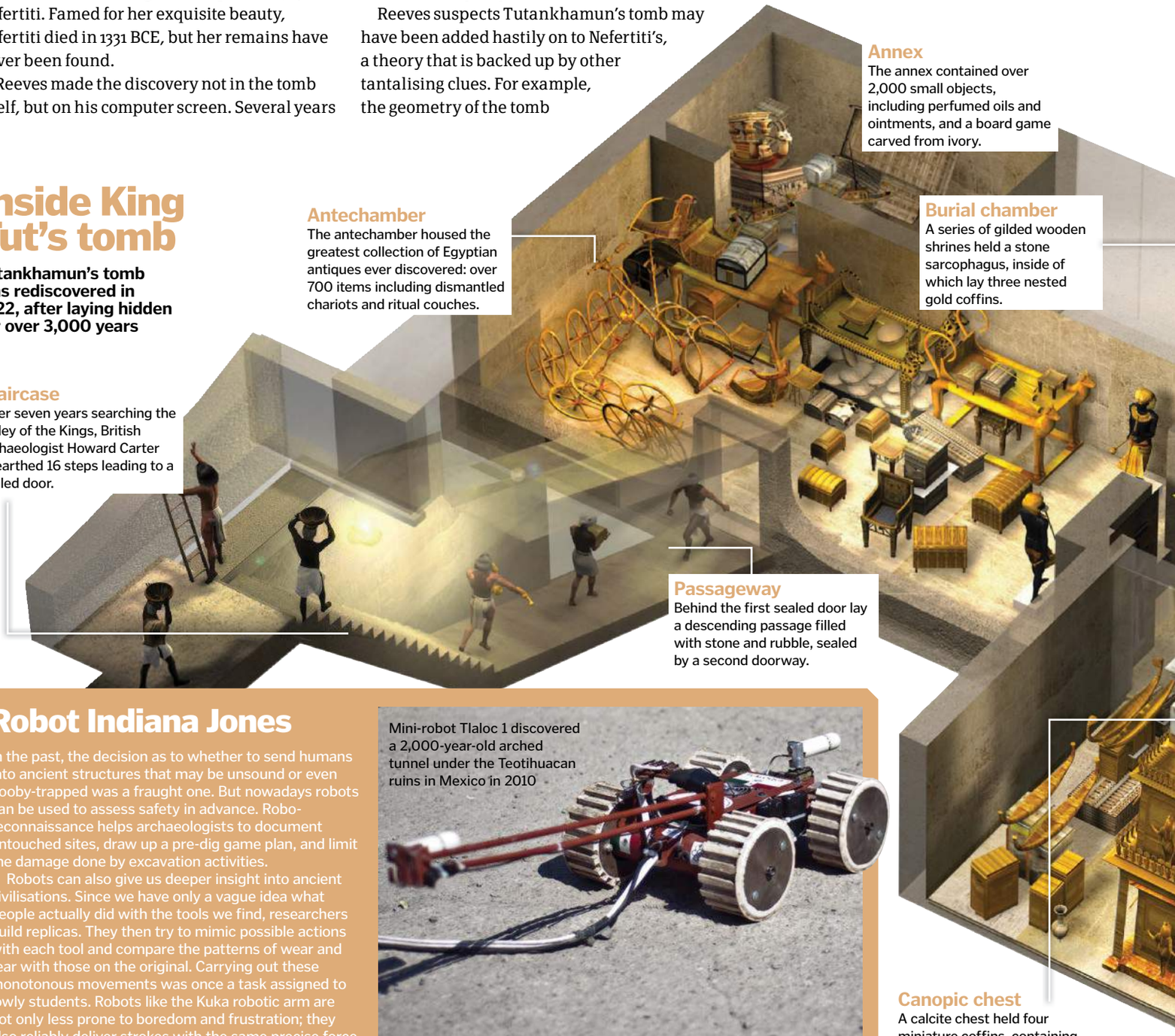
It is almost a century since the extraordinary discovery of the tomb of Egyptian Pharaoh Tutankhamun captured the attention of the entire globe. However, stunning new evidence suggests that the final resting place of the famous 'boy king' may still have secrets to reveal. The tomb could contain a pair of hidden rooms, according to British Egyptologist Nicholas Reeves, one of which might be the burial chamber of King Tut's stepmother, Queen Nefertiti. Famed for her exquisite beauty, Nefertiti died in 1331 BCE, but her remains have never been found.

Reeves made the discovery not in the tomb itself, but on his computer screen. Several years ago, a Spanish design firm made high-resolution scans of the tomb's interior, intending to build a replica. Studying these detailed scans, Reeves was astounded to see faint outlines of a pair of 'ghost' doorways, almost invisible to the naked eye. Egyptian Antiquities Minister, Mamdouh el-Damaty, told a press conference in Cairo in late September 2015 that, if true, the discovery would "overshadow [that] of Tutankhamun himself."

Reeves suspects Tutankhamun's tomb may have been added hastily on to Nefertiti's, a theory that is backed up by other tantalising clues. For example, the geometry of the tomb resembles those of Egyptian queens, not kings, and the opening of what is believed to be Nefertiti's mausoleum is decorated in an older style than the three other walls. In October 2015, Egyptian officials began performing ultrasensitive radar scans of the site. They have detected that the northern wall is a different temperature to other parts, which could indicate a chamber lies behind it.

Inside King Tut's tomb

Tutankhamun's tomb was rediscovered in 1922, after laying hidden for over 3,000 years



Annex
The annex contained over 2,000 small objects, including perfumed oils and ointments, and a board game carved from ivory.

Antechamber
The antechamber housed the greatest collection of Egyptian antiques ever discovered: over 700 items including dismantled chariots and ritual couches.

Burial chamber
A series of gilded wooden shrines held a stone sarcophagus, inside of which lay three nested gold coffins.

Staircase
After seven years searching the Valley of the Kings, British archaeologist Howard Carter unearthed 16 steps leading to a sealed door.

Passageway
Behind the first sealed door lay a descending passage filled with stone and rubble, sealed by a second doorway.

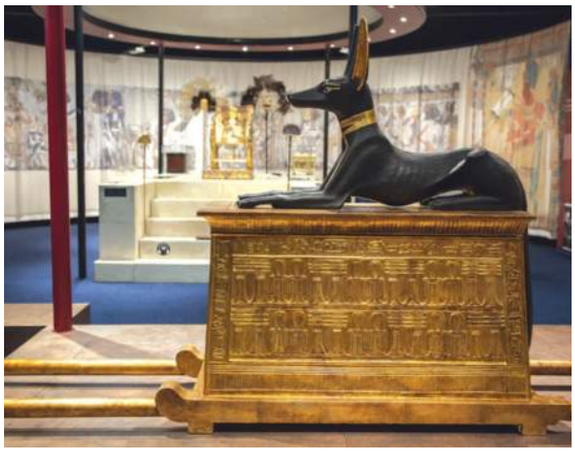
Canopic chest
A calcite chest held four miniature coffins, containing the embalmed internal organs of the boy king.

Robot Indiana Jones

In the past, the decision as to whether to send humans into ancient structures that may be unsound or even booby-trapped was a fraught one. But nowadays robots can be used to assess safety in advance. Robo-reconnaissance helps archaeologists to document untouched sites, draw up a pre-dig game plan, and limit the damage done by excavation activities.

Robots can also give us deeper insight into ancient civilisations. Since we have only a vague idea what people actually did with the tools we find, researchers build replicas. They then try to mimic possible actions with each tool and compare the patterns of wear and tear with those on the original. Carrying out these monotonous movements was once a task assigned to lowly students. Robots like the Kuka robotic arm are not only less prone to boredom and frustration; they also reliably deliver strokes with the same precise force every single time.

Mini-robot Tlaloc 1 discovered a 2,000-year-old arched tunnel under the Teotihuacan ruins in Mexico in 2010



Mummy
At the centre of it all lay the mummified body of the 19-year-old King, adorned with a golden burial mask.

Secret doorway 1
This is the proposed location of a hidden storage room, marked by faint vertical scratches in paintwork.

Secret doorway 2
Queen Nefertiti's tomb is thought to have been here, hiding under the noses of Egyptologists for almost a century.

Treasury
The treasury contained over 5,000 valuable items, guarded by a statue of the god Anubis, including a fleet of model boats to transport the king to the afterlife.

Become a treasure hunter!

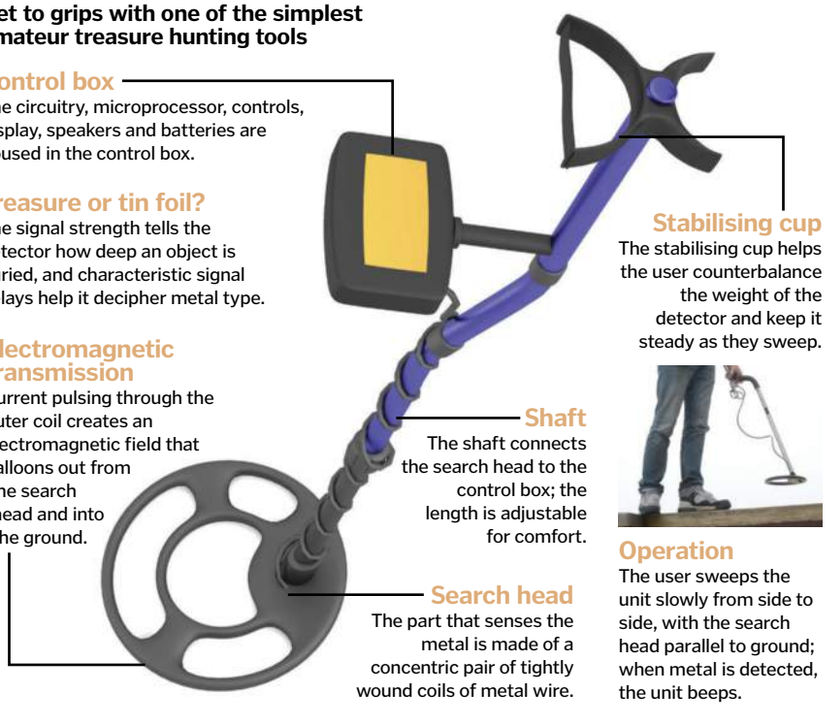
Why should archaeologists have all the fun? If you're feeling inspired to search for buried treasure yourself, you'll first need to draw up a good pirate map. In real terms, this means scouring history books, online forums and Google Maps for tips and clues.

If treasure legends and hearsay leave you bewildered, you could join the search for Forrest Fenn's bona fide fortune instead. This famous art dealer decided to have some fun in his old age, and hid a chest of treasures worth up to $3 million (approx £2 million) in the mountains of Santa Fe, New Mexico. Clues to its location, in the form of a poem, are written in his 2010 memoir.

Next you'll need to get yourself some kit. Hobby drones can easily be fitted with aerial cameras and other sensors; Microsoft has designed an app that turns a humble smartphone into a handheld 3D scanner; and of course, no treasure hunter should be without a good, old-fashioned metal detector.

How metal detectors work

Get to grips with one of the simplest amateur treasure hunting tools



Control box
The circuitry, microprocessor, controls, display, speakers and batteries are housed in the control box.

Treasure or tin foil?
The signal strength tells the detector how deep an object is buried, and characteristic signal delays help it decipher metal type.

Electromagnetic transmission
Current pulsing through the outer coil creates an electromagnetic field that balloons out from the search head and into the ground.

Shaft
The shaft connects the search head to the control box; the length is adjustable for comfort.

Search head
The part that senses the metal is made of a concentric pair of tightly wound coils of metal wire.

Stabilising cup
The stabilising cup helps the user counterbalance the weight of the detector and keep it steady as they sweep.

Operation
The user sweeps the unit slowly from side to side, with the search head parallel to ground; when metal is detected, the unit beeps.

The world's best treasure hunting spots

1 Where: English countryside
What: Roman coins
England's green land sparkles with ancient Roman currency.

2 Where: Florida Keys, US
What: Wreck diving
Frequent hurricanes have made these waters rich with treasure.

3 Where: Baguio, Philippines
What: Yamashita's gold
The General's WWII spoils are stashed in 175 mountain caves.

4 Where: Mongolia
What: Genghis Khan's tomb
History's greatest conqueror is buried with his untold riches.

5 Where: Central California, US
What: Panning for gold
There's still plenty of gold to be had in the 'golden state'.

6 Where: South African countryside
What: Kruger gold stash
The president hid his gold reserves during the 1900 British takeover.

Espresso machines explained

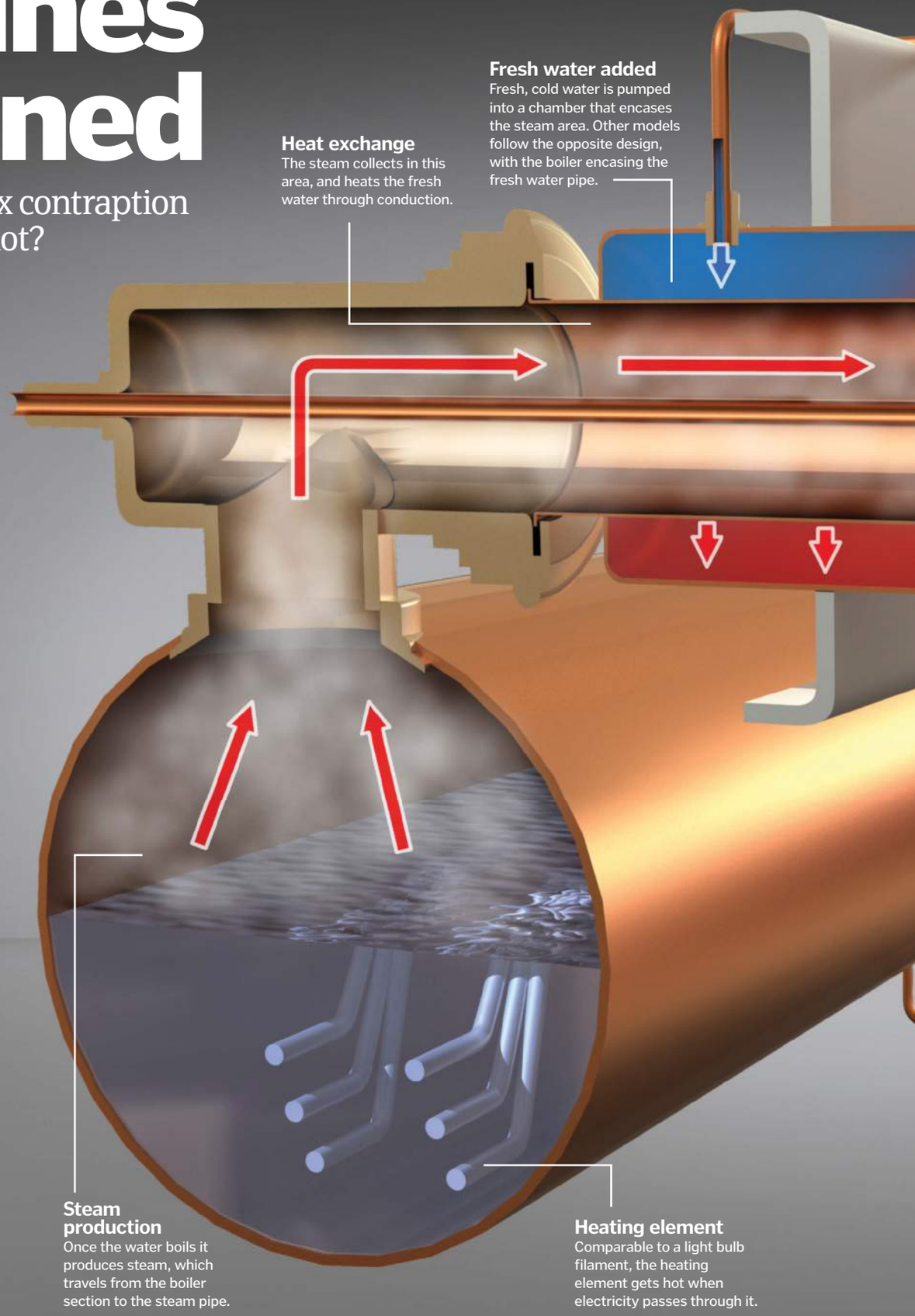
How does this complex contraption produce the perfect shot?

"A temperature change of only one degree has a noticeable effect on taste"

Brewing the ideal espresso demands the perfect balance of grind, temperature and pressure. In order to produce the best coffee the water must be precisely heated; experts will argue a temperature change of only one degree has a noticeable effect on taste.

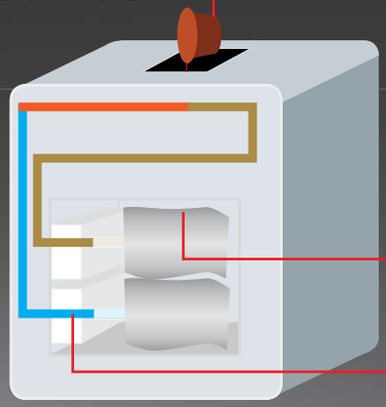
Typically, a jet of hot water between 88 and 93 degrees Celsius (190 and 200 degrees Fahrenheit) passes through the ground coffee at a pressure of nine atmospheres (nine times normal atmospheric pressure). Anything hotter than this will burn the coffee, giving it a sharper, more bitter taste. When espresso machines were first invented, pressure was created by working a lever, which compressed the steam inside the machine. Modern machines have replaced this system with a set of pumps and valves, which automatically compress the steam to create the required pressure.

Inside an espresso maker, a boiler containing a heating element will bring water to the required temperature. Many machines now employ a heat exchange system, which involves cold water being drawn through a pipe within the boiler chamber. The hot water and steam in the boiler heat the pipe and the water within it by conduction until it reaches the perfect brewing temperature. It is then forced through the coffee grounds at high pressure – generated by a pump – to extract the beans' flavour and aroma. Once filtered to remove most of the grounds, the coffee pours through the nozzle and into your espresso cup, ready to enjoy. The steam from the boiler can also be directed to a steam wand and used to heat and froth milk for other beverages such as cappuccinos.



Out-of-this-world coffee

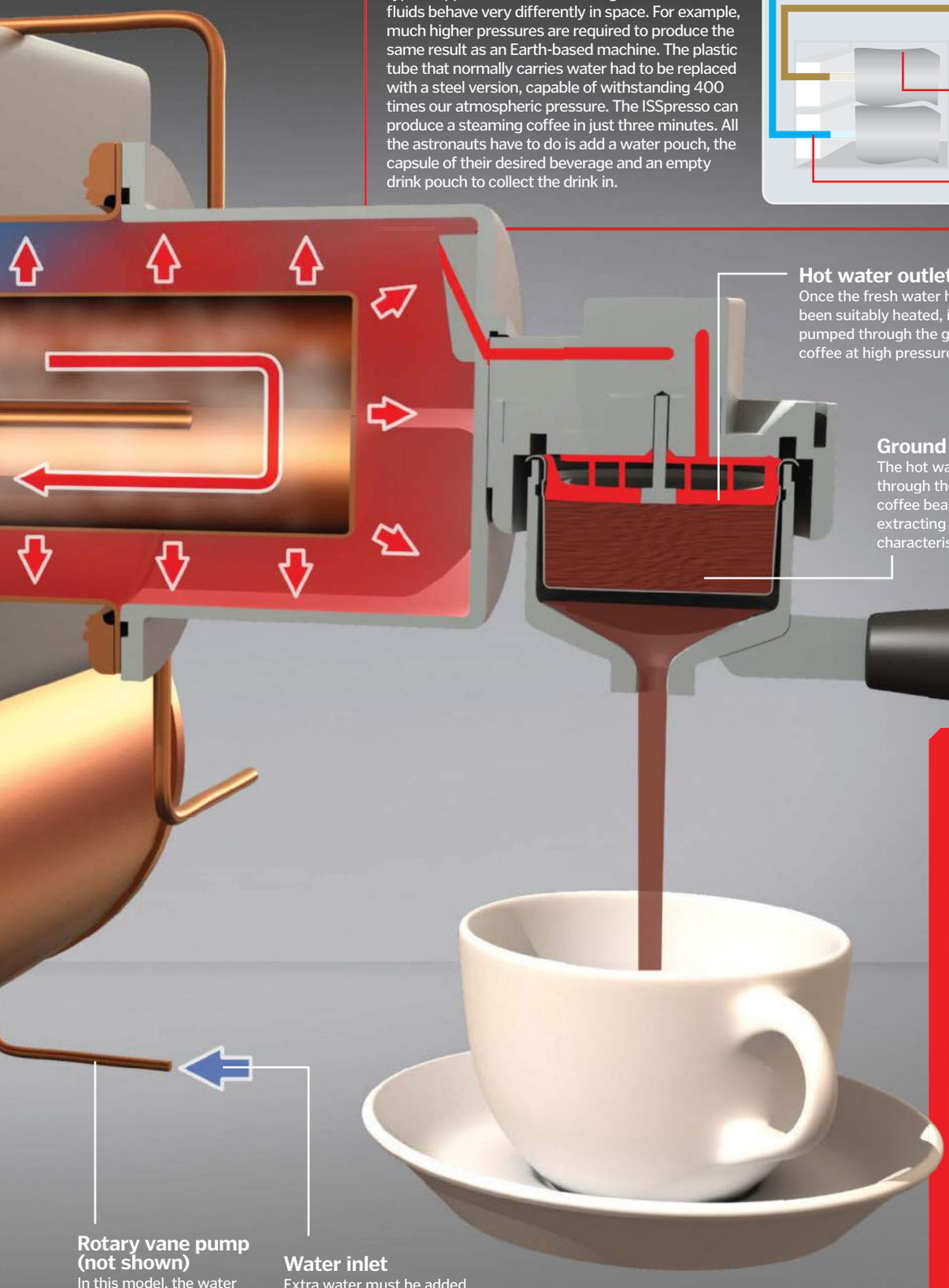
Now crew members on the International Space Station can boldly brew where no man has brewed before. The Italian Space Agency teamed up with Argotec and Lavazza to build a microgravity coffee machine – the ISSpresso. The entire design for a typical appliance had to be re-engineered because fluids behave very differently in space. For example, much higher pressures are required to produce the same result as an Earth-based machine. The plastic tube that normally carries water had to be replaced with a steel version, capable of withstanding 400 times our atmospheric pressure. The ISSpresso can produce a steaming coffee in just three minutes. All the astronauts have to do is add a water pouch, the capsule of their desired beverage and an empty drink pouch to collect the drink in.



Coffee capsule
The same Lavazza coffee capsules used on Earth are compatible with the ISS machine.

Coffee aroma
A pressure difference inside the pouch ensures that the fresh coffee smell is released when a straw is inserted.

Water added
Water is added, pressurised and then heated to the appropriate temperature.



Hot water outlet
Once the fresh water has been suitably heated, it is pumped through the ground coffee at high pressure.

Ground coffee
The hot water passes through the ground coffee beans, extracting their characteristic flavour.

Rotary vane pump (not shown)
In this model, the water supply is pressurised by being sent through a rotary vane pump.

Water inlet
Extra water must be added occasionally to maintain the perfect ratio of hot water and steam in the boiler.

How quickly can you make a coffee?

For many coffee lovers, the faster they can get their hands on a brew, the better. The AeroPress device boasts a new method of producing an espresso-strength coffee in less than a minute. After placing the device on top of a mug and filling it with coffee and hot water, you insert the plunger and press down slowly but firmly to force the water through the ground beans. Bored of waiting for his drip coffee maker to deliver the goods, inventor Alan Adler developed the plunging method and fine paper filter to produce a high quality taste.

Illustration by Adrian Mann

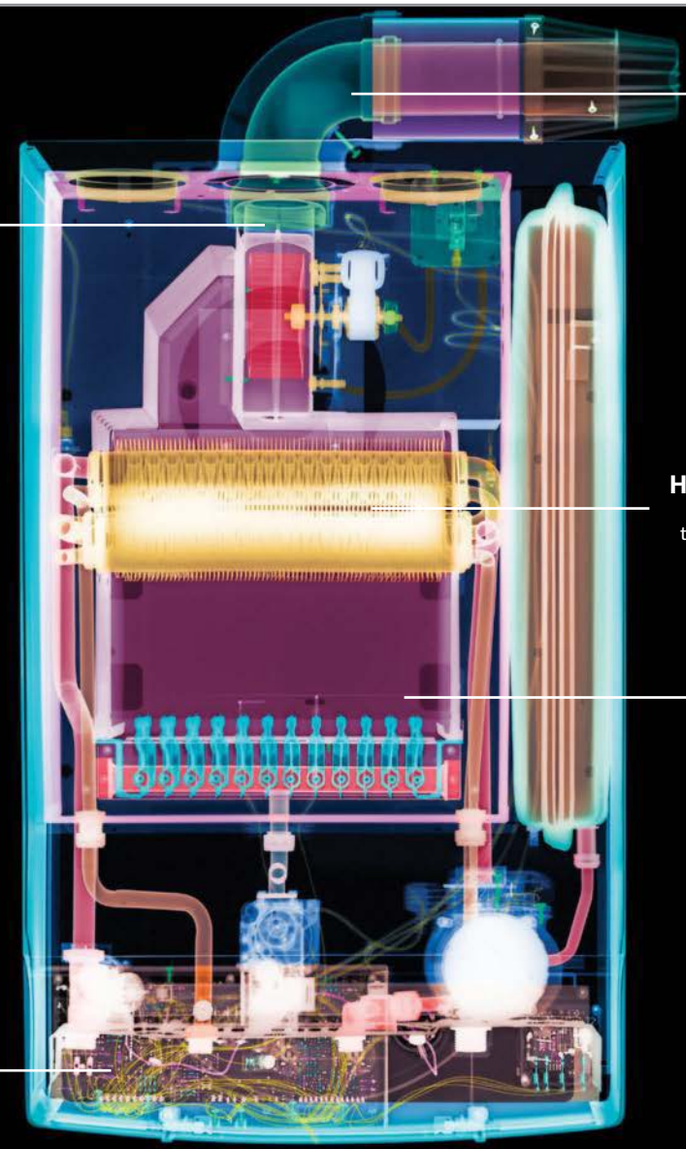
Combination boilers

How does this essential household appliance heat water on demand?

Combination boilers work to heat your radiators and provide unlimited hot and cold water. They have become an increasingly popular choice in our homes, as they heat water directly from the mains supply, making them highly economical as they only heat the water that you use.

As soon as you turn on your hot tap, water feeds through a series of pipes that pass through the boiler. The boiler detects that you've turned on the tap and instantly ignites the gas burner. This heats the water by conduction as it passes through a heat exchanger. Within a matter of seconds, the water reaches the required temperature, flows through the pipes and out of the tap. Once you turn the hot tap off, a signal is relayed to the boiler, switching off its heating system so that fuel isn't wasted.

The main benefit of combination boilers is that they deliver hot water on demand. There's also no need for water storage tanks as with other boiler types, making them great for small homes where space is limited.



Flue
Exhaust gases leave the boiler through a type of chimney called a flue.

Extraction aid
A small fan at the base of the flue helps to propel exhaust gases out of the boiler.

Heat exchanger
This is where the thermal energy from the hot gas is transferred to the water, heating it to approximately 60°C (140°F).

Electronic controls
The electronic control system enables the user to set the temperature and times they want their central heating on.

Combustion chamber
Gas enters this chamber through a series of small jets, and is lit by an electric ignition system.

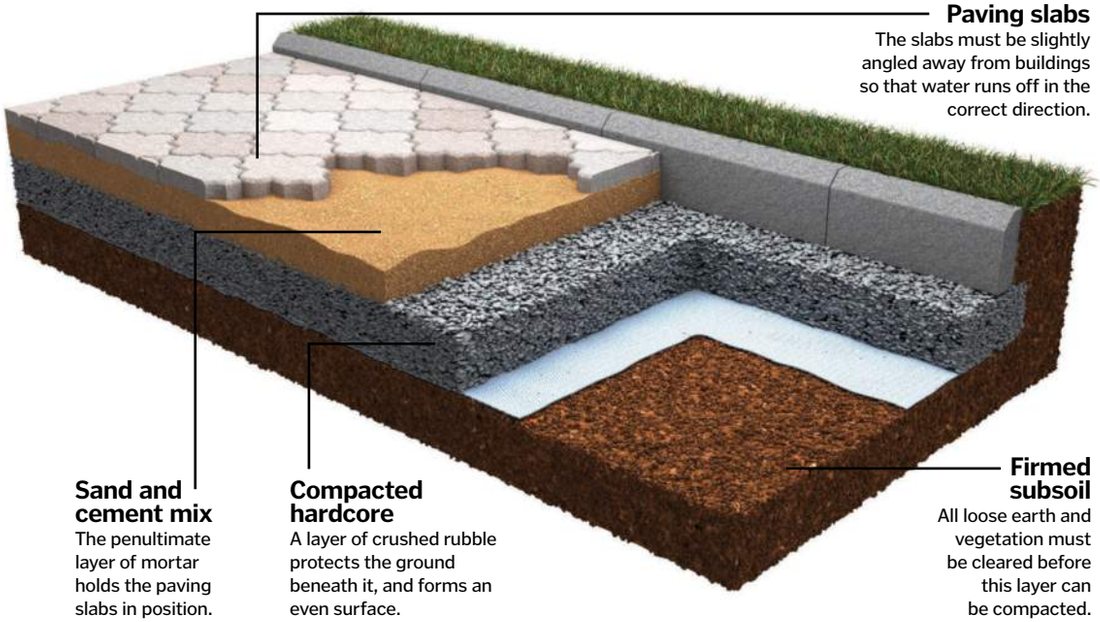
Laying paving

How to prepare the foundations for your perfect patio

Laying a new patio or a paved walkway requires considerable know-how to get right. Traditional paving comprises four distinct layers, which must all be laid precisely to give an even end product.

First, the ground beneath the paving must be cleared of all debris and vegetation; if left this will rot and cause the paving to become uneven. Mixed grit and stone is then added to form a layer called hardcore. This rugged material protects the ground, and can be easily compacted to provide a level surface.

Dry sand or a cement and sand mix is then laid on top. It's imperative to use coarse sand rather than building sand, as this is too soft and would wash away in the rain. Finally, the paving slabs can be laid and tapped into position with a rubber mallet.



Paving slabs
The slabs must be slightly angled away from buildings so that water runs off in the correct direction.

Sand and cement mix
The penultimate layer of mortar holds the paving slabs in position.

Compacted hardcore
A layer of crushed rubble protects the ground beneath it, and forms an even surface.

Firmed subsoil
All loose earth and vegetation must be cleared before this layer can be compacted.

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Geothermal heating

How can heat from the Earth be used to warm our homes?

Every hour, the Sun beams enough energy directly onto our planet to satisfy our global energy needs for a year. The ground absorbs almost half of this solar energy, resulting in a relatively constant, moderate temperature just below the surface. However, above ground it's a very different story; air temperatures vary drastically from season to season, which means traditional, air source heating and cooling systems have to use a lot of energy to maintain a constant temperature in your home.

By contrast, a geothermal heat pump aims to take advantage of the steady ground temperature, using a loop of piping buried underground to transfer heat throughout the building. A mix of water and antifreeze is circulated through the loop, which slowly absorbs heat from the warm ground. It only needs to be heated by a few degrees for the process to work.

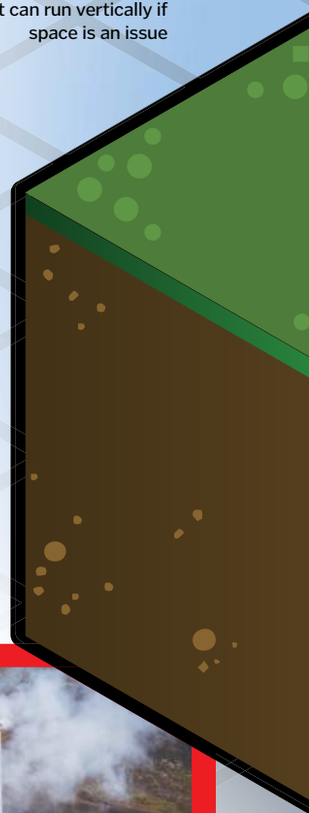
This liquid is then fed into a heat exchanger, where the heat energy it gained underground is transferred to a refrigerant – a compound that can easily absorb heat from a separate source. The refrigerant boils at a lower temperature than water, producing a gas that is then fed into a compressor.

Here, the gas is pumped into a very small compartment, increasing its pressure which in turn raises its temperature. The hot gas is then transferred into a condenser, where it is cooled down until it turns back into a liquid. During this cooling process, the heat removed from the gas is used to warm the water in your heating system – ready to be transported around your home. Once it has cooled, the ground-loop fluid is recycled back to the underground pipes, where it can absorb more thermal energy and start the process again.

A geothermal heat pump is an incredibly efficient way of heating a building. Better still, geothermal energy is available 365 days a year, unlike other renewable energy sources like solar and wind energy, which depend heavily on the weather.

"A geothermal heat pump aims to take advantage of the steady ground temperature"

The piping is usually installed in a flat loop, but can run vertically if space is an issue



Hot springs in Japan

As winter descends on Hell's Valley, the temperature in this Japanese mountain range can drop to -20 degrees Celsius (-4 degrees Fahrenheit). The freezing climate makes the nearby hot springs very popular; not with the local people as you might imagine, but with macaques. Japanese macaques live further north than any of the other non-human primates, and as such have to endure the lower temperatures found at higher latitudes. However, they've found a cunning way of keeping warm. Also known as snow monkeys, they bathe regularly in the geothermal springs, and seem to have adapted to spending plenty of time in this aquatic environment. This activity not only helps them keep warm, but is also used to build social relationships.

Tourists flock to see the macaques bathe in these geothermal springs every year

Generating geothermal electricity

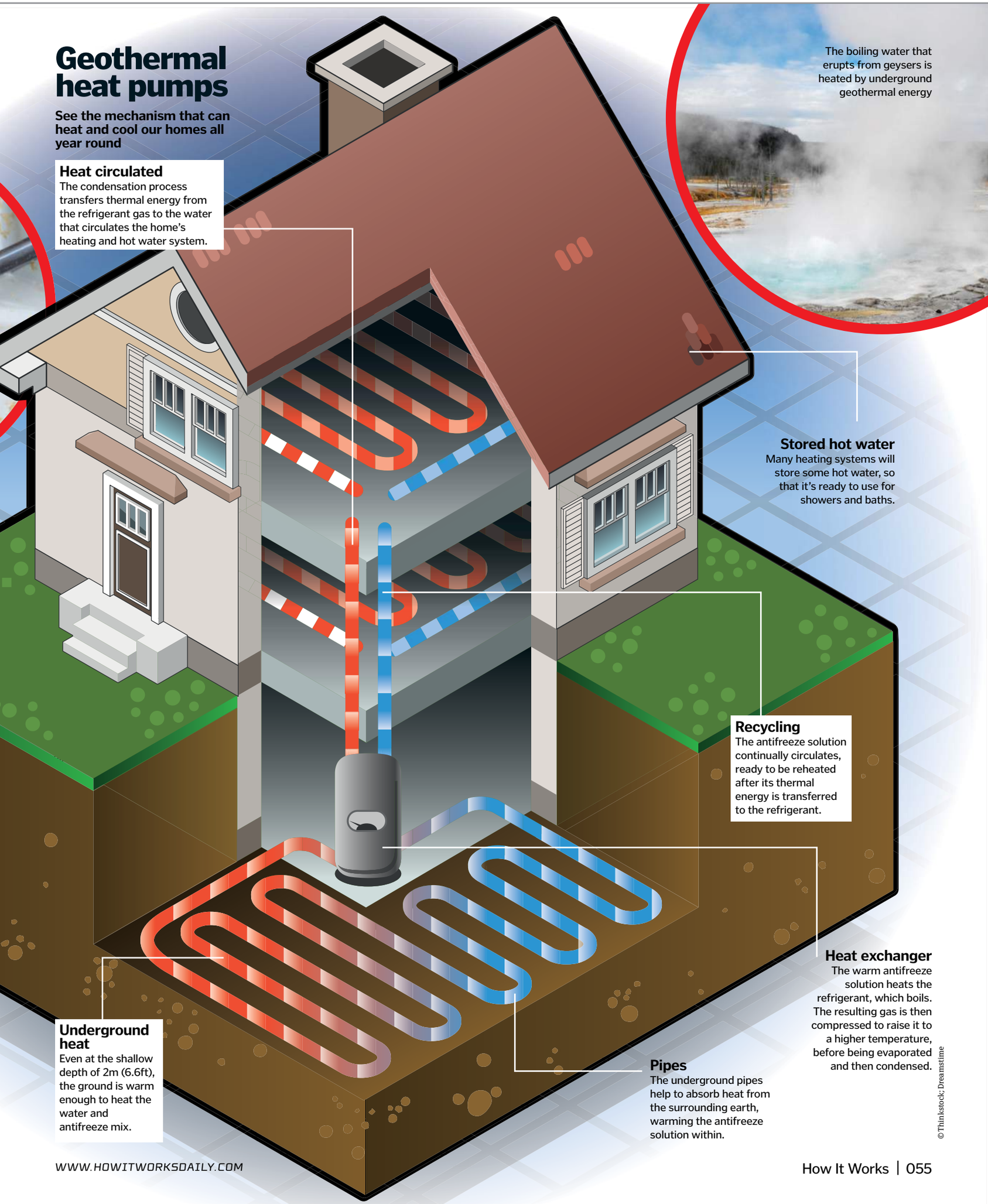
Accessing the geothermal energy from Earth's internal heat on a large scale is a complex task. Drilling down into underground reservoirs requires planning and precision; it's often necessary to go deeper than 1.6 kilometres (one mile) to find sufficiently hot water and steam sources.

There are three different types of geothermal power plants, all of which use steam to spin turbines that generate electricity. The simplest type is a dry steam plant, which uses the hot steam directly from an underground reservoir. Flash steam plants use the incredibly hot water, bringing it up to the surface via a well. When it reaches ground level, they rapidly depressurise the water so that it's 'flashed' into steam. The last type is a binary cycle plant, which passes moderately hot water through a heat exchanger, transferring its heat to a liquid with a lower boiling point. This liquid is then heated until it turns to steam.

Geothermal electricity is currently produced in more than 20 countries around the world

Geothermal heat pumps

See the mechanism that can heat and cool our homes all year round



Heat circulated
The condensation process transfers thermal energy from the refrigerant gas to the water that circulates the home's heating and hot water system.

The boiling water that erupts from geysers is heated by underground geothermal energy

Stored hot water
Many heating systems will store some hot water, so that it's ready to use for showers and baths.

Recycling
The antifreeze solution continually circulates, ready to be reheated after its thermal energy is transferred to the refrigerant.

Heat exchanger
The warm antifreeze solution heats the refrigerant, which boils. The resulting gas is then compressed to raise it to a higher temperature, before being evaporated and then condensed.

Pipes
The underground pipes help to absorb heat from the surrounding earth, warming the antifreeze solution within.

Underground heat
Even at the shallow depth of 2m (6.6ft), the ground is warm enough to heat the water and antifreeze mix.

Noise-cancelling headphones


Active noise-cancelling headphones can block out up to 70 per cent of background noise

How does this audio technology use speakers to reduce ambient sound?

If you've ever tried listening to music on a flight, you'll be familiar with battling the constant droning of the jet engines. Noise-cancelling headphones can reduce this ambient sound, helping you to enjoy listening to music or watching an in-flight movie. There are two ways to achieve this effect, known as active and passive noise reduction. The latter is the simplest method, as it blocks sound waves with layers of high-density foam. This is good for masking high frequency sounds such as a loud bang, but the headphones will struggle to stop resonances at a lower frequency.

Active noise-cancelling headphones also use special materials, but go one step further and create their own sound waves too. Tucked inside the earpiece is a small microphone that detects ambient sound and feeds it to a digital processor, which analyses the sound wave's composition. It uses this information to create a sound wave that's the complete opposite of the one it analysed. This 'anti-sound' wave has the same sized peaks and troughs as the background noise, but they are inverted.

These anti-sound waves are then played back from a small speaker in the ear cup, actively blocking the ambient sound waves through a phenomenon known as destructive interference. When the incoming sound wave is at a peak, the anti-sound wave is at a trough, and the sum of these two waves adds to zero, resulting in minimal external sound reaching the wearer's ears.

Active noise-cancelling

How does the system hear, analyse and block unwanted sound?

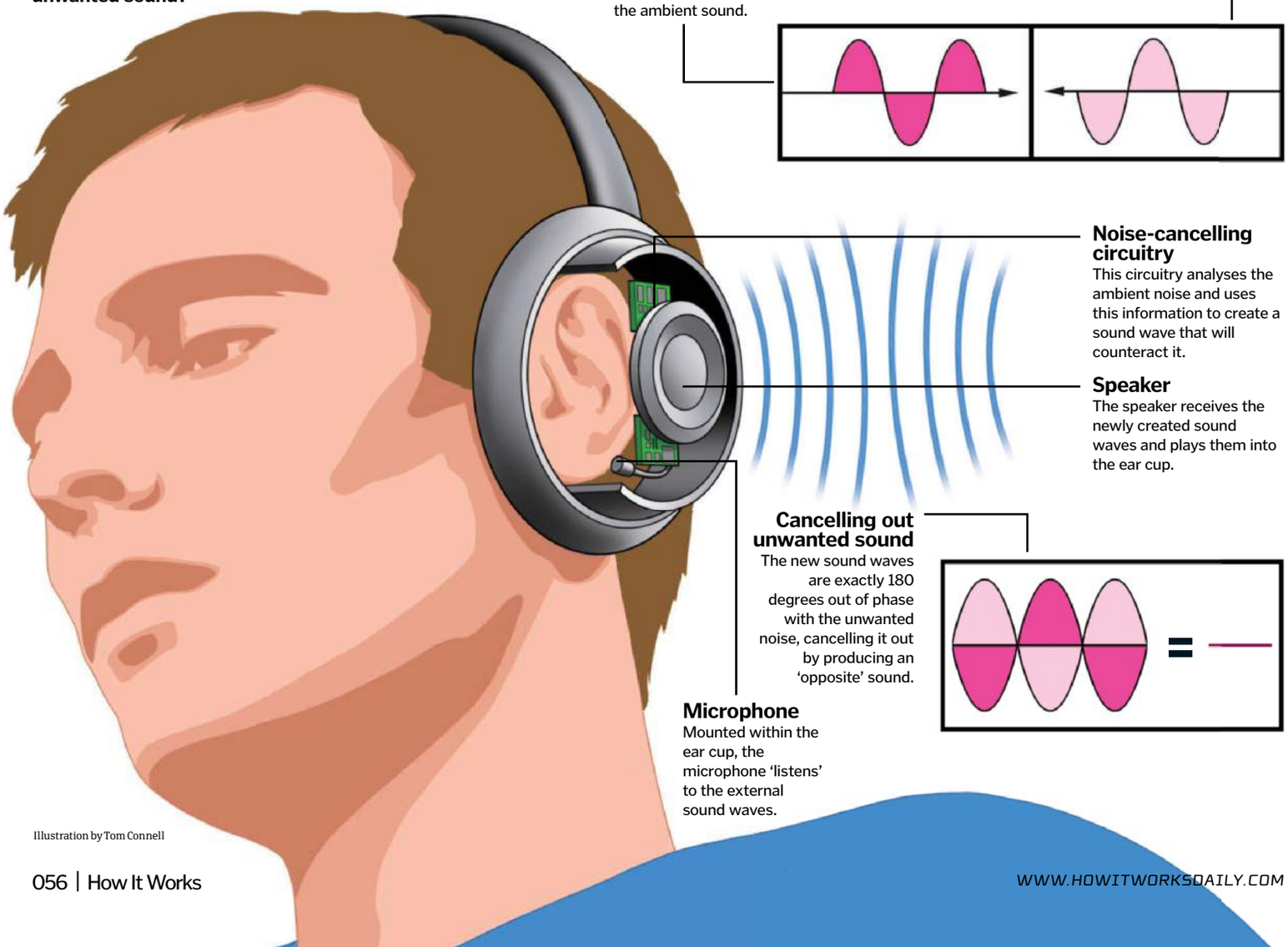


Illustration by Tom Connell

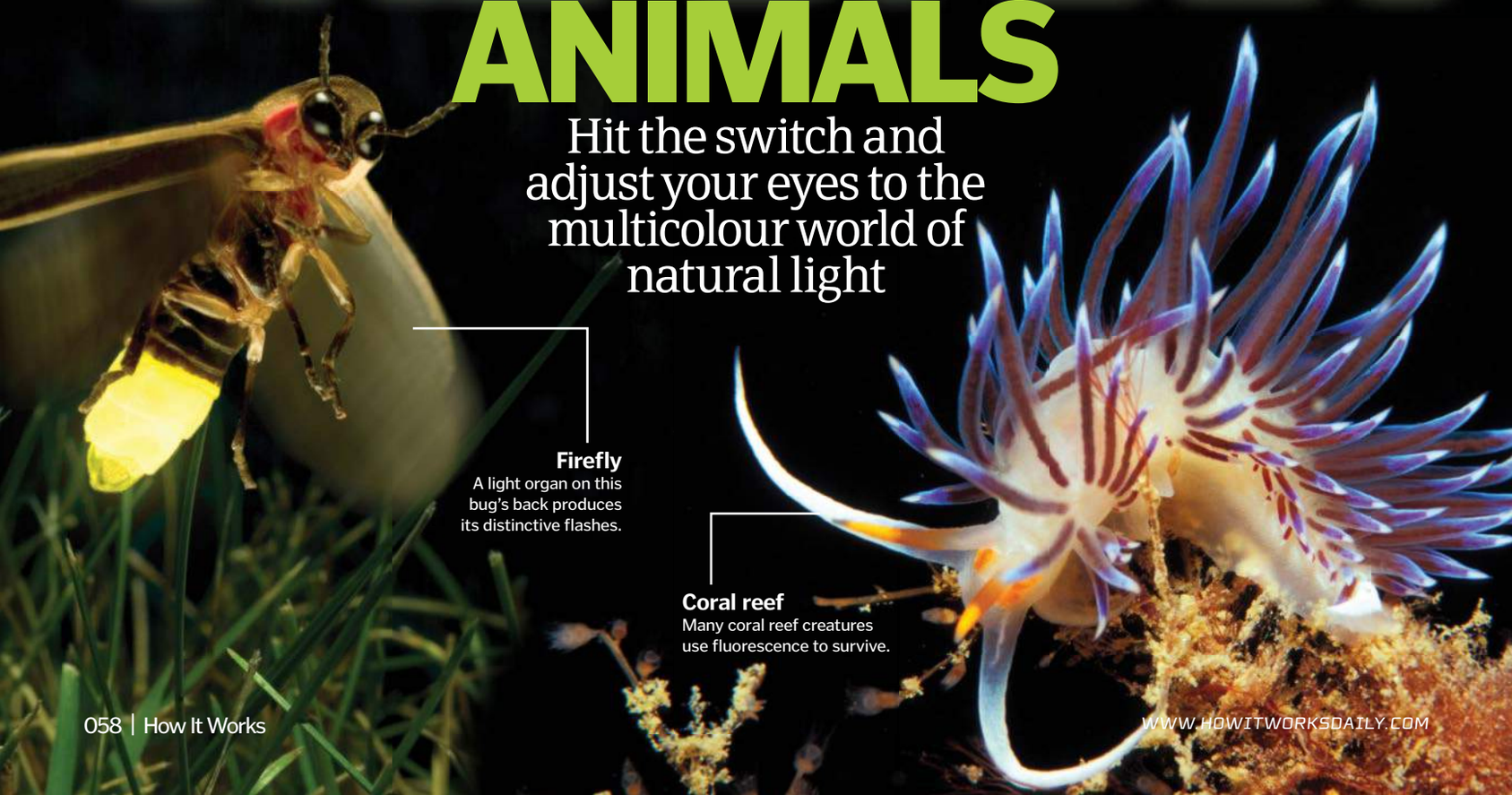
Jellyfish
Some jellyfish species use flashes of light to scare off potential predators.

Bobtail squid
This squid uses bioluminescent bacteria to provide light-up camouflage.

Scorpion
Scorpions fluoresce under UV light, but no one really knows why.

AMAZING GLOW-IN-THE-DARK ANIMALS

Hit the switch and adjust your eyes to the multicolour world of natural light

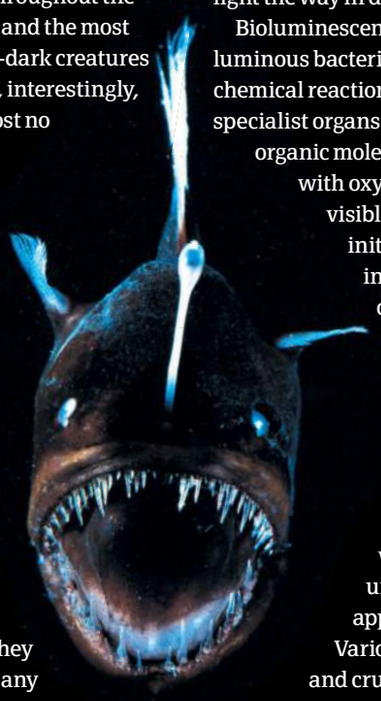


Firefly
A light organ on this bug's back produces its distinctive flashes.

Coral reef
Many coral reef creatures use fluorescence to survive.

Imagine walking through a forest at night and encountering a swarm of dancing lights floating in the air. It may look like magic, but it is one of the most astounding features of the natural world: bioluminescence. The flying flickers of light are a biochemical reaction exhibited by tiny fireflies, as they light up the night in their efforts to find a mate.

Bioluminescence is found throughout the animal kingdom and beyond, and the most extensive array of glow-in-the-dark creatures can be found in the ocean. Yet, interestingly, freshwater habitats have almost no bioluminescent organisms.



Although modern science has allowed us to explore the inner workings of how this incredible biology occurs, bioluminescence has been fascinating humans for thousands of years. References to natural creatures glowing in the dark appear in the folklore of many different cultures, in Scandinavia, China and India to name a few. In the fourth century BCE, ancient Greek philosopher Aristotle noted, "some things, though they are not in their nature fire nor any species of fire, yet seem to produce light." Similarly, during the first century CE, Roman scholar Pliny the Elder even documented that he took the slime of a jellyfish from the Bay of Naples and rubbed it on his walking stick, where it lit the way "like a torch."

As Aristotle himself noticed, bioluminescence is a 'cold light', which means that unlike the glow that is produced by electrical light bulbs, which also produces waste heat energy, the bioluminescent reaction is almost 100 per cent efficient and produces very little heat. There are two ways that animals are able to produce this light: by possessing the right biological means to make it themselves, or by hosting bioluminescent bacteria that work with the animal to provide their flashy light show. These bioluminescent bacteria can also be free-living, or parasitic, attaching themselves to a host and making it glow unwittingly.

One animal that has a mutually beneficial relationship with these bacteria is the tiny bobtail squid, a cephalopod just a few centimetres long, found in coastal waters of the Pacific. The squid uses the bacteria's blue-green glow to camouflage itself in the water column by matching the glow of moonlight from above - a technique known as counter illumination. In return, the squid's body provides the bacteria with a sugary solution to feed on. Every morning, the squid will expel 95 per cent of its bioluminescent bacteria, ensuring that it stops glowing while it rests. By the time night returns, the bacteria have repopulated, reaching a large enough concentration to begin glowing again. This is also an interesting use of bioluminescence as camouflage, rather than to light the way in darkness.

Bioluminescent creatures that don't rely on luminous bacteria create their own light via chemical reactions. These animals often have specialist organs called photophores in which organic molecules known as luciferin react with oxygen to produce photons of visible light. These reactions can be initiated by various factors, including chemical, neurological or mechanical triggers.

Bioluminescence is not the only method employed by the animal kingdom to glow in the dark. Many animals also shine through fluorescence, where light is absorbed and then emitted at a different wavelength. For example, under a UV light, scorpions appear a neon turquoise colour. Various species of corals, jellyfish and crustaceans also have fluorescent properties, as does the Japanese eel – which is one of the only known vertebrates to exhibit this trait.

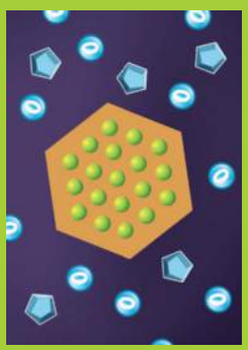
On top of this, animals can also use phosphorescence, which is chemically similar to fluorescence, but the light is absorbed and (unlike fluorescence) still continues to glow once the light source is removed. Many sea creatures will exhibit a combination of the three light-up methods, but phosphorescence is often too weak to see with the naked eye or is overshadowed by the other two, much brighter, methods of natural illumination.

In the ocean, the glowing show of colour very often includes neon hues of blues and greens. This is because these are the wavelengths that travel the furthest in the depths, ensuring that a creature's lights are fit for purpose. However, the colours are also tailored to their specific function. Animals use their glow-in-the dark capabilities for defence, to ward off predators or to dazzle attackers. Lights help to attract both food and mates, and can even provide a cloak of camouflage. It is possible that there are also benefits for the non-luminous ocean beings such as sperm whales, who dive so deep to hunt that scientists believe they may rely on the bioluminescence of their prey in order to track down a meal.

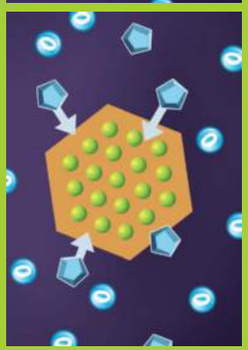
The science behind bioluminescence

Bioluminescence is produced by a chemical reaction involving a molecule known as luciferin

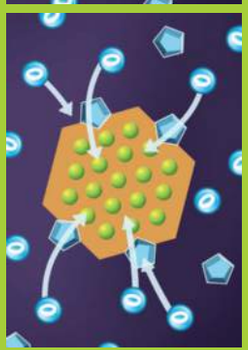
1 Ingredients
In general, for a bioluminescent reaction to occur, an organism needs a luciferin molecule, luciferase (the catalyst which enhances the reaction) and oxygen to oxidise the luciferin.



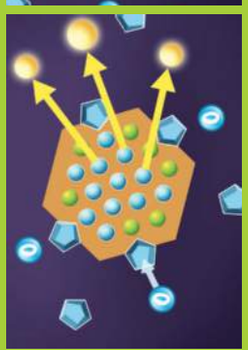
2 Catalyst
A catalyst is a substance that increases the rate of a chemical reaction. In this case, the catalyst is called luciferase. This is the general term for an enzyme that helps a light-emitting reaction to take place.



3 Oxidisation occurs
The luciferase provides a pathway for the oxygen so that it can combine with the luciferin more easily. The oxygen then oxidises the luciferin by adding oxygen molecules to it.



4 Light is produced
When luciferin reacts with oxygen, photons of light are released. When this reaction happens collectively in a creature's photophores, it produces the amazing natural light displays.



5 Reaction by-products
The bioluminescent reaction results in by-products: carbon dioxide and a compound called oxyluciferin – the new name for the oxidised luciferin molecule.

How natural illumination can benefit us

As a naturally occurring phenomenon, that in its simplest form requires just oxygen to work, bioluminescence can also have many applications in our everyday lives. We can harness this amazing light-emitting process for medical, military and commercial uses. Natural fluorescence, too, is being developed as an increasingly useful tool.

Scientists are able to use naturally fluorescent proteins to track the spread of viruses and diseases in rodents, and also to watch the development of cell tissue in amazing rainbow colours. This has potential for allowing us to understand and treat human disease.

We can also use our knowledge of bioluminescence to genetically modify plants so they glow. Although the science of this is still very much in its infancy, this use of bio-light could go as far as adapting trees to glow in place of streetlights, saving valuable fossil fuels. Scientists at Edinburgh University have already created glowing potatoes that illuminate under a black light when they are dehydrated, working as a marker for farmers to precisely monitor their crops. Although there is controversy surrounding genetically modified foods, the science behind such developments is still incredible.

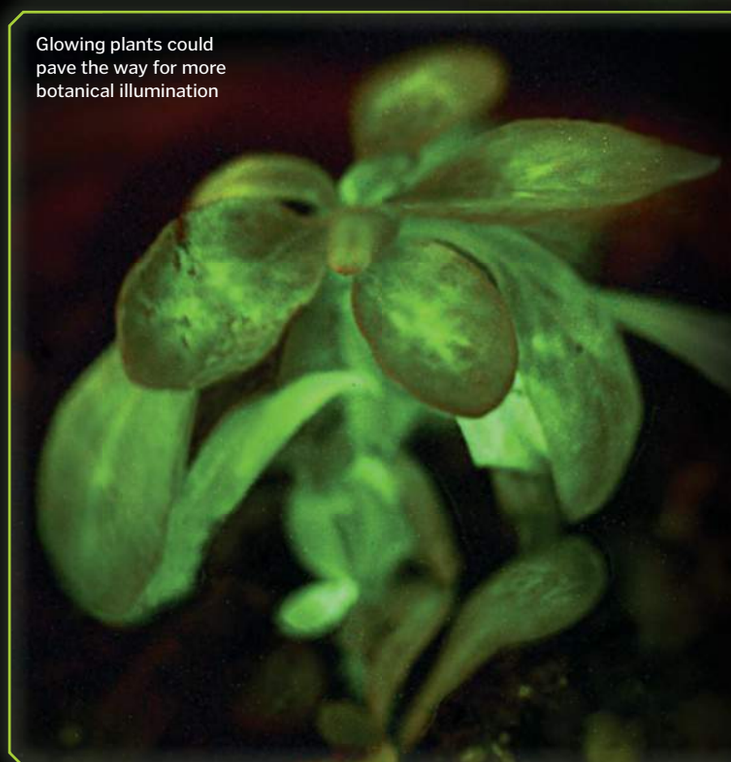
There might also be military uses for bioluminescence. Certain species of plankton often bioluminesce when they are disturbed, which could give away the whereabouts of otherwise stealthy submarines, or disrupt other covert naval operations.

Then there are, of course, plenty of commercial applications to light up our daily lives as well. For example, biotech company BioLume in North Carolina hope to develop a range of incredible luminous sweet treats – such as lollies, chewing gum and drinks – as well as personal care products including toothpastes, soaps and bubble baths that glow in the dark.

Glowing mice

A fluorescent protein derived from jellyfish known as Green Fluorescent Protein (GFP) has revolutionised cell biology. It glows bright green under blue and UV light, and can be used as a versatile marker to highlight a huge array of biological processes. The protein can be cloned (so it doesn't need to be harvested from live jellyfish) and then the gene sequence for GFP can be added to an organism's genome. In turn, this makes specific areas of cells (that scientists want to study) 'glow'. This means scientists are much better able to witness and understand the growth of tissue, from nerve cells in the brain to the spread of cancerous tumours, which has huge potential in medical research.

Glowing mice could help researchers combat a huge array of diseases



Glowing plants could pave the way for more botanical illumination

Glowing greenery

The company Bioglow has been working on an energy-saving alternative to streetlights, by developing a plant that glows on its own. Named Starlight Avatar, a pot plant called Nicotiana alata has had a gene for bioluminescent bacteria inserted into its genome, creating an 'autoluminescent' plant that emits a yellow-green light independently.

Lighting up the deep

Bioluminescence is found throughout the water column, from the surface waters to the deepest ocean trenches. As the light fades, the amount of biological illumination begins to increase. It's thought that around 90 per cent of deep-sea animals use some form of bioluminescent light to hunt, defend themselves and find mates.

Comb jelly

Despite their name, these tiny organisms are not jellyfish. Comb jellies have paddle-like appendages that propel them, which flash with rainbow light as they move. This happens when incident light is scattered through the moving cilia, but many species are also bioluminescent, capable of glowing blue-green.

Anglerfish

There are many species of anglerfish, with the majority possessing a large, bioluminescent lure, like a glowing fishing rod. This menacing appendage helps the females to attract prey. Male anglerfish are much smaller and do not have lures, instead they latch on to females like parasites and provide sperm for reproduction.

Why do animals glow?

Squid send out a burst of light to deter would-be predators

Flashlight fish use super-bright light organs beneath their eyes to lure in and illuminate prey

Different firefly species can be identified by their flashing patterns

DEFENCE

Defensive bioluminescence is used to deter predators. Creatures such as squid use a sudden burst of light to startle their attacker, and some animals also employ a 'smoke screen' effect to enable a quick getaway.

OFFENCE

Bioluminescence can be used to attract prey, or to find it by lighting it up. Animals such as some siphonophores and flashlight fish will use their bioluminescence to lure prey towards them, and then enjoy the spoils.

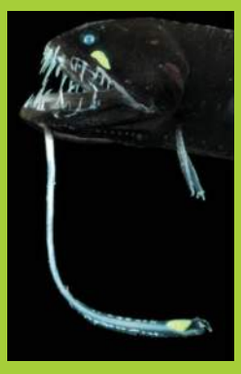
ATTRACTION

Bioluminescence plays a key role in the courtship of fireflies, who have light organs in their lower abdomen. Males perform a light show to attract females, who will flash back in response if they like what they see.

"We can harness this amazing light-emitting process for medical, military and commercial uses."

Black dragonfish

This fearsome looking creature has light-producing cells along its entire length, and it can light up suddenly when disturbed or threatened. However, this fish has an extra trump card: it can glow with near-infrared light, which many other deep sea species are unable to detect, allowing it to launch stealth attacks upon its prey.



Tomopteris

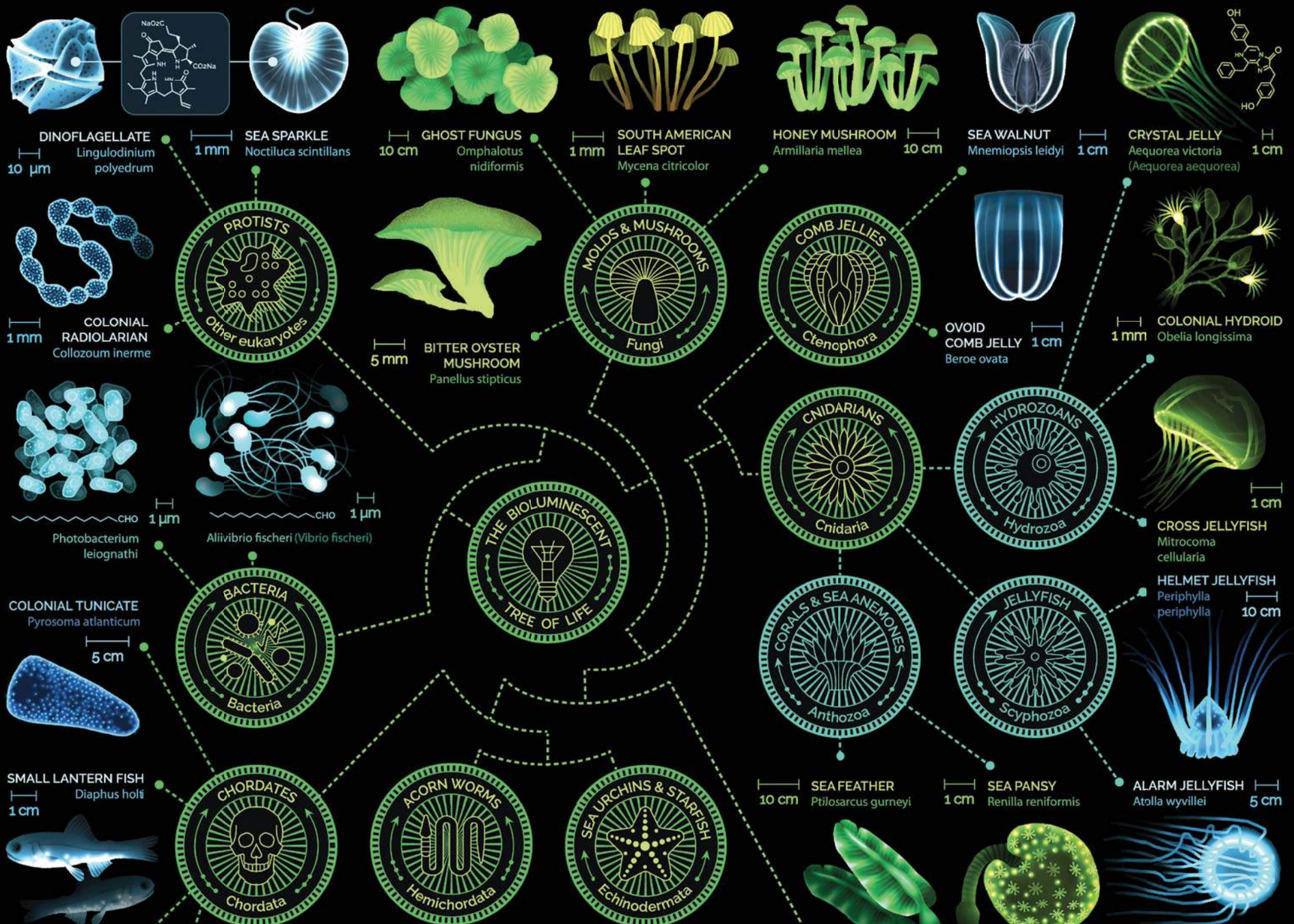
These beautiful-looking creatures are swimming polychaete worms. They have bioluminescent cells that allow them to flash bright colours, and there are species that can even produce yellow light, which is rare in the deep. Tomopteris are also capable of shooting bioluminescent particles that allows them to get away from predators.

Mauve stinger jellyfish

In German, the mauve stinger jellyfish's name translates as 'night light', reflecting its amazing bioluminescent capabilities. When it becomes startled or trapped, the flight response sets off the chemical reaction so it can release a glowing trail of mucous in its wake as it tries to make an escape.

Living lights

The natural world is decorated with an army of organisms using bioluminescence to glow




PROTOSTOMES
Protostomata
WORMS & LEECHES
Annelida
ARTHROPODS
Arthropoda
INSECTS
Insecta
CENTIPEDES & MILLIPEDES
Myriapoda
MOLLUSCS
Mollusca
CRUSTACEANS
Crustacea
SNAILS & SLUGS
Gastropoda
SQUID, CUTTLEFISH, OCTOPI
Cephalopoda
ASSISTED BIOLUMINESCENCE
Most shallow water glowing fishes use other bioluminescent species to glow.
PARCHMENT WORM
Chaetopterus variopedatus
1 cm
POLYNOID SCALEWORM
Harmothoe lunulata
5 mm
LUMINOUS EARTHWORM
Diplocardia longa
5 cm
GENJI FIREFLY
Luciola cruciata
5 mm
SOUTH AMERICAN RAILROAD WORM
Phrixothrix hirtus
1 cm
FIRE CENTIPEDE
Orphnaeus brevilabiatus
1 mm
SIERRA LUMINOUS MILLIPEDE
Motyxia sequoiae
5 mm
BRITTLE STAR
Ophiopsila californica
5 mm
COMMON PIDDOCK
Pholas dactylus
1 cm
KRILL
Euphausia pacifica
5 mm
SEA FIREFLY
Vargula hilgendorfii
(Cypridina hilgendorfii)
1 mm
ACORN WORM
Ptychodera flava
1 cm
SWEEPER FISH
Parapriacanthus beryciformes
(ingested Cypridina)
1 cm
COPEPOD
Metridia lucens
100 µm
HATCHET FISH
Argyropelecus hemigymnus
1 cm
EYELIGHT FISH
Photoblepharon palpebratus
(symbiotic bacteria)
1 cm
SEA SNAIL
Hinea brasiliana
1 mm
DEEP SEA SHRIMP
Sergestes similis
1 cm
STOPLIGHT LOOSEJAW
Malacosteus niger
1 cm
PLAINFIN MIDSHIPMAN
Porichtys notatus
(ingested Cypridina)
5 cm
FIREFLY SQUID
Watasenia scintillans
1 cm
GLOWING SUCKER OCTOPUS
Stauroteuthis syrtensis
5 cm
FRESHWATER LIMPET
Latia neritoides
1 cm
FLYING SQUID
Symplectoteuthis luminosa
5 cm
A chart of selected bioluminescent species, including all known luciferin, luciferase, and photoprotein structures. Based on the textbook Bioluminescence: Chemical Principles and Methods (Revised Edition) by Nobel laureate Professor Osamu Shimomura.
2014 ELEANOR LUTZ

Carving a stone forest

Water is the architect of this ruthless rocky environment

The jagged maze of Tsingy de Bemaraha

Towering needles of limestone dominate this Madagascan nature reserve, carved out over millennia by the flow of water

From above, the formidable jagged pinnacles of the Tsingy de Bemaraha look like a stone forest. Found on the west coast of Madagascar, it is an incredible feat of natural sculpting. The rock formations are a karst system – a geological term used when a landscape is made up of soluble rock, such as limestone, that is scoured away and dissolved over time by the flow of water.

About 2 million years ago, the area was a lagoon, beneath which lay a deep bed of limestone. Over millennia, tectonic activity and falling sea levels caused this rock to be elevated above the water, exposing the soft limestone rock to the elements. On the surface, wind and rain lashed down onto the limestone and gradually wore away the softer upper layers, leaving the harder parts standing in tall spires – this is how the pinnacles were formed.

Deep below the surface layers, groundwater spread along faults in the rock, eroding as it went, which has created horizontal caves that slice their way across the Tsingy de Bemaraha. Groundwater also infiltrated vertically along joints in the rock, and the water cut away large caverns. As the caverns expanded in different layers, the supporting rock weakened and collapsed along the same joints. This created huge 'grikes' – vast, straight canyons that drop down into the rock. These can be up to 122 metres (400 feet) deep.

This vertical process along with the horizontal weathering has created an intricate network of caves, tunnels and bridges that extend throughout the rocky maze. Their size varies greatly, making it a very tricky environment for humans to explore, but many animals and plants call this stony labyrinth home.

Life in the Tsingy

Thanks to the jagged rocks and deathly steep grikes, the wildlife of the Tsingy has been left virtually undisturbed by humans. Over the millennia, plenty of organic matter has collected in the deep canyons, providing an excellent supply of nutrients as well as shelter and protection for all manner of exotic plant species. Tall trees reach skyward between the pinnacles, which also host many species of lemur.

Colourful birds cling to the rocks, and countless insect species navigate the towering caverns. Lizards sun themselves on the many ledges, and beneath the surface, an array of aquatic creatures swim in the maze of channels.

It's thought that there is much left to discover from within this wildlife refuge. It is also estimated that up to 85 per cent of the wildlife here is endemic (only found in Madagascar) and of that, 45 per cent is locally endemic (only found in the Tsingy Nature Reserve).

The Tsingy provides refuge for an amazing array of species, such as the Madagascan kestrel

© Alamy

"The Tsingy is an incredible feat of natural sculpting"

The life of a pine tree

Discover how a lone pine can create an entire forest

Vast forests of pine trees can be found in many different regions, from the snowy mountains of North America to the open plains of Europe. These hardy evergreen trees can grow in environments that many others can't, favouring acidic or sandy soils and rocky regions at high altitudes.

When exposed to plenty of sunlight, pines can grow up to a towering 80 metres (262 feet) and live for hundreds of years. One bristlecone pine in California is thought to be 5,000 years old, making it one of the oldest trees in the world, but most are cut down long before they reach this ripe old age.

Although pines are native to temperate regions in the Northern Hemisphere, some species have been introduced to southern continents as a valuable source of timber, an industry worth billions of pounds. The young pines that don't go on to become fence panels and furniture usually end up as Christmas trees in homes across the world. Over 77 million pines are planted for this purpose each year, and take six to eight years to reach optimum Christmas tree size. However, when left to their own devices, pine trees grow to have long, slender trunks – almost unrecognisable as the same trees we decorate with tinsel and fairy lights – and use pine cones to reproduce. Each tree uses both male and female structures to create the next generation.

Squirrels help to disperse pine seeds when they bury the cones as a winter food supply

From cone to tree

How does a pine tree reproduce?

1 Male and female
Mature pine trees are monoecious, meaning that they have both male and female reproductive structures called strobili.

2 Male strobili
The male strobili form in the bottom part of the tree, and contain microsporocytes that develop into pollen.

3 Pollen released
In spring, the male strobili release their pollen, which then falls to the ground.

4 Female strobili
The pollen is carried by the wind up to the female strobili, which grow at the end of the tree's branches.

5 Pollination
Once the pollen lands on the female strobili, it finds its way into the ovules to fertilise the egg cells.

6 Fertilisation
It takes about a year for fertilisation to occur, in which time the strobili develop into woody pine cones.

7 Pine cone
Once matured, the woody cones open up, exposing the seeds that sit at the end of each of their scales.

8 Germination
The seeds are dispersed by animals or the wind, and under the right conditions, germinate and develop into seedlings.

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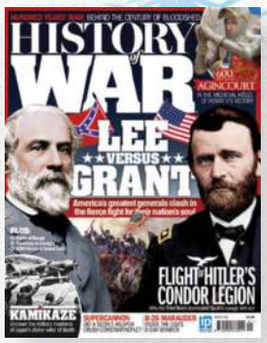

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VICTORIAN SÉANCES DEBUNKED

In an era of steam trains and suspension bridges, many Victorians still looked to the supernatural for solutions

Across North America and Western Europe, the 19th century was one of seemingly irreconcilable contrasts. Engineering and science were ascendant, but the Victorian era was as much a world of spirits as it was steam trains. For all the promises of a better future, the age was a morbid one – visit a graveyard and the memorials that loom the largest, like props from an old horror film, will most likely date from the mid-to-late 1800s. It's no coincidence that this was the era of the spooky story too, from Charles Dickens' *A Christmas Carol* in Britain to Edgar Allan Poe's *The Masque of the Red Death* in the United States.

The Industrial Revolution brought with it an increasing rate of accidents and pollution, infant mortality was high, war and disease were rife – a litany of ills tore families apart, leaving a grief that many con artists were only too happy to profit from. Spiritualism – the belief that ghosts exist and we can communicate with them – came into being as a movement in 1848, via three American sisters: Leah, Margaret and Kate Fox. The trio hit the headlines with a sensational (and totally bogus) ghost story in which they had communicated with the spirit haunting their home using a series of knocks – one for 'yes', two for 'no'. Rumours soon spread that the spirit belonged to a murdered peddler whose body was hidden in the cellar.

The girls were quickly promoted as mediums, making a fortune by holding crowded séances where they would contact the deceased at the audience's command.

With this business model behind them, mediums began to spring up all over the United States and then in Britain, holding intimate gatherings in darkened homes or more outlandish spectacles in music halls and theatres – for a fee.

Some might have been well-intentioned, genuinely convinced they could contact the dead, but most were frauds, using dim gaslight, hidden accomplices, slight of hand and ingenious contraptions to hoodwink the vulnerable.

Sadly, many people were only too willing to believe. With technology advancing at an unbelievable pace, anything seemed possible. If they could send messages between continents via telegraph cables, then why couldn't they communicate with the afterlife? If perfect recreations of living people could be captured by photographers, why couldn't they take pictures of the dead too?

SPEAKING TO THE DEAD

How creative con artists became the talk of Victorian society

Like the Fox sisters who kicked off an interest in spiritualism with their tall tales, cynical con artists produced a wide repertoire of gimmicks, including phantom knocking with their feet, painted balloons masquerading as ghosts, objects 'floating' around with the help of fishing lines, violins with weighted bows which appeared to play notes by themselves, or 'phantom music' from a hidden gramophone.

Low light, apparently better for ghosts, helped conceal the true nature of the con; total darkness was even better. Mediums encouraged the participants to keep their eyes closed, allowing them to reach out and touch people with 'ghostly hands', or even with their shoes to create the illusion of levitation.

These appear like bizarre conjuring tricks now and it seems strange that anyone would have been taken in by something that required your eyes to be closed in order for it to work, but in the 19th century, they gripped society.

Inside the séance

The tricks and tools of the fraudulent medium

Take my hand

The lights are turned down or put out completely and the medium invites the participants to hold hands, or hold the wrist of the person to their left or right, to prove there's no foul play.

The spirits reach out

Using either their own hand, a waxwork replacement, a stuffed glove or a telescopic rod to reach across the table, the medium can now pretend a spirit is touching the audience.

Sound effects

Should the ghostly tradesman have required it, the sound of sawing wood could be made by dragging the trumpet across the floor or moving the collapsible sections up and down within each other.

Voices from the void

In other séances the trumpet would be the centre of attention rather than a sneaky secret, channelling spooky whispers from the beyond – either the medium was a ventriloquist or he had a hidden accomplice.

The spirits arrive

Pretending to enter a trance to communicate with the spirits, the medium twitches and jerks one hand loose. Scrambling for it in the dark, the participants either side don't realise they've been tricked into taking the same hand.

Ghostly wheezing

One account from 1925 detailed a ghostly farmer being summoned from the grave. The sound of him pumping water was produced by a collapsible trumpet being surreptitiously opened and closed.

Spectral lights

Mysterious glowing orbs, objects or even faces could be produced by adding a dab of luminous paint and mounting on a stick, which allowed them to hover above the table.

Deadly Drowning

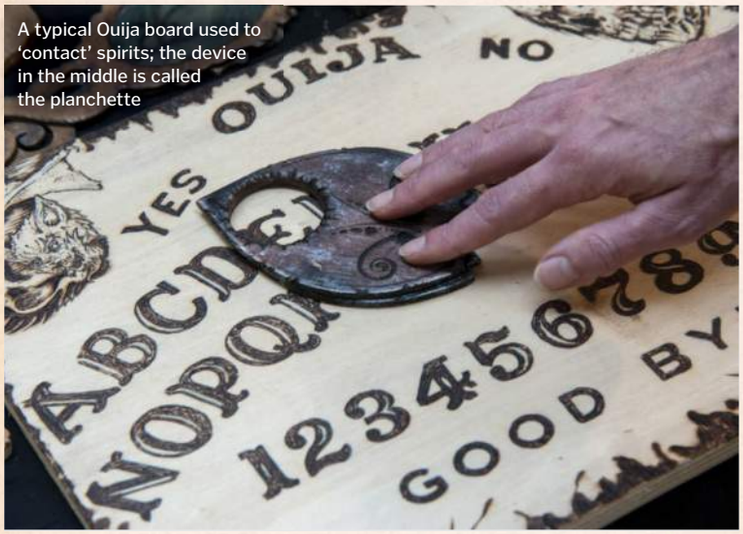
Most distressingly, one account recalls a medium sneaking a bowl of water onto the table and blowing through a straw to simulate drowning. He added, "Help me! Help me!" for good measure.

Illustration by Geri Ford/Art Agency

A SÉANCE IN A BOX

A descendant of the Victorian 'talking board' used to spell out messages from the spirits, the Ouija board was patented in 1890 by businessman Elijah Bond. He saw the huge interest in spiritualism and a gap in the market for a séance that believers could do for themselves.

Now an iconic part of popular culture, inspiring moral panics and horror movies alike, this elegantly designed board was based around the alphabet, the numbers one to ten, and the words 'hello', 'goodbye', 'yes' and 'no'. Users placed their hands on a heart-shaped 'planchette', which would then spell out words. Its mystical sounding name, meanwhile, is simply the French and German words for 'yes' sandwiched together.



A typical Ouija board used to 'contact' spirits; the device in the middle is called the planchette

GHOST HANDS OR YOUR HANDS?

Michael Faraday, best known for discovering the link between electricity and magnetism, conducted an experiment in 1853 to discover why tables moved during séances. By taking bundles of card, each layer progressively smaller so he could accurately mark their position in pencil, he invited volunteers to place their hands on the card so he could see the 'spirits' at work. The cards moved from the top down, rather than sliding out from the bottom due to the movement of a table, suggesting the pressure was being applied by living hands rather than ghostly ones.

Faraday had stumbled across the ideomotor response, which is when muscle movements take place without conscious thought. This is the key to debunking Ouija boards, spirit writing, water diving and countless other acts of the supposed supernatural.

Although the ideomotor response isn't a deliberate reaction, it can be influenced. American psychologist Joseph Jastrow discovered in the 1890s that once the Ouija planchette picked out the first letter, the participants began to anticipate the next and the ideomotor response followed suit until a complete word had been spelt out.

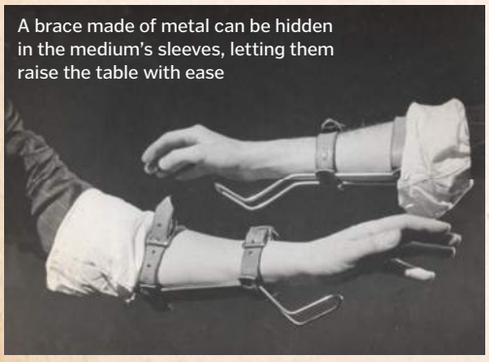
Michael Faraday demonstrated the ideomotor response, when muscles move without deliberate thought

TURNING THE TABLES

One of the most basic tricks in the medium's arsenal, spirits could appear to rap on the table (easy enough to do with your foot, as the Fox sisters proved), move it violently with a kick or levitate it gently in response to simple 'yes' or 'no' questions.

Levitation in small tables was simple. The medium slid their foot out of their shoe so that the other participants could still feel the shoe's presence in the dark and think they hadn't moved, while they brought up their knee and lifted the table for a few seconds – the wobble making it all the more spooky.

The more ingenious medium might even have put their fingertips on the tabletop and used a sort of metal 'fork lift' strapped to their forearm and covered by their sleeves to scoop the table up.



A brace made of metal can be hidden in the medium's sleeves, letting them raise the table with ease

Stage magician William S Marriot demonstrates how the medium can be seen to lift a table

Even by the standards of spiritualism, ectoplasm was unconvincing and many mediums were prosecuted

SPEWING SLIME

The showstopper for the overambitious medium, ectoplasm was a 'spiritual energy' expelled by the medium as proof of gathering spirits.

The medium used cloth such as bandage gauze soaked in soap, gelatine or egg white, in order to be seen barfing up ghost puke in the conveniently dim light of a séance. Shapes could also be formed, such as ghostly hands – actually a lady's glove coated in luminous paint.

This malarkey was so blatantly nonsense that mediums found themselves facing fraud charges when the 'ectoplasm' was later found stuffed into their pockets.

GETTING SPOOKS ON CAMERA

Introduced in the 1850s, the photographic plate made photography quicker and easier than ever, bringing it firmly into the reach of the middle classes. The supernatural came hot on its heels, with the first reported photograph of a ghost appearing soon afterwards, courtesy of William Henry Mumler.

These thin glass plates were a precursor to film reel. The image was burnt into the glass by a coat of silver halide, activated on contact with the light as soon as the camera shutter opened. Keen to find evidence that their loved ones were still with them, the subject would pose for his photo without realising that the photographer had left a plate from a previous shot in the camera, merging the two images so that the subject was seen to be standing side-by-side with their deceased relatives.

Mumler found himself in court for fraud in 1869 when some of his customers later recognised their 'ghosts' in the street. He was acquitted, but his career was finished.

Double exposure was used to create spectral figures – some more convincing than others

THE UNLIKELY GHOSTBUSTERS

While many great writers and visionary scientists lined up to pour scorn on spiritualism during the Victorian age and the 1920s, perhaps its most ardent critics came from an altogether different background: showbiz!

Alongside circus kingpin P T Barnum and numerous other stage magicians, Harry Houdini was appalled to see the innovations he had used to entertain being twisted and perverted.

Houdini visited séances in disguise – often accompanied by undercover policemen – and called out mediums on their con, throwing on the lights and tearing off their disguises to make arrests.

Sometimes debunking mediums was all too easy; when one claimed to have summoned the ghost of Abraham Lincoln, the well-read Houdini simply asked questions about the President's life that the fraud was unable to answer correctly.

Other mediums offered Houdini a greater test of his cunning and on one occasion he wore a tight bandage on his knee all day in order to make his skin extremely sensitive to the slightest movement. It was incredibly painful but when he attended the séance he was able to feel the medium fumbling around under the table for her props.

A 1909 poster from one of Harry Houdini's shows debunking spiritualism

RICHARD HODGSON
1855-1905

Though the Australian-born investigator was a firm believer in spirits, he was rigorous in his approach and led the charge to debunk fraudulent mediums. Hodgson recreated séances in order to explain to the audience where they had been fooled. Sadly, these recreations could be so convincing that they actually had the opposite effect on the audience.

Hodgson served as the secretary of the American Society for Psychical Research

Inside Boeing's 377 Stratocruiser

Fly back to the Fifties, where aircraft reached new heights in luxury

In the years following World War II, cutting-edge military technology was put to commercial use. In the late 1940s, Boeing unveiled the 377 Stratocruiser, an airliner based on the B-29 Superfortress Bomber, complete with the warplane's speed and design. One of the most significant advancements of the B-29 that the 377 utilised was Boeing's signature '117' airfoil design. The wings had flaps that could be retracted while flying to help minimise drag and allow higher speed, which kept flights as economical as possible.

Four 3,500-horsepower piston engines drove the 377's enormous propellers, helping it soar to a cruising altitude of 9,750 metres (32,000 feet). Piston engines are characterised by multiple tubes, each containing a separate solid cylinder known as a piston, which moves back and forth inside it. When the fuel ignites within each tube, it causes the gases within to heat up and expand. This forces the piston to drive forward, moving the connecting rod and turning the crankshaft, which in turn spins the propeller.

The 377's engines were actually quite unreliable, due to their complex, 28-cylinder composition. The plane was designed to be able to fly with only three working engines, but this did not save the plane from catastrophe. Between 1951 and 1970, Stratocruisers suffered 13 hull-loss accidents, with many fatalities. This is one of the reasons why the 377 was retired commercially in favour of jet aircraft.

The golden age of air travel

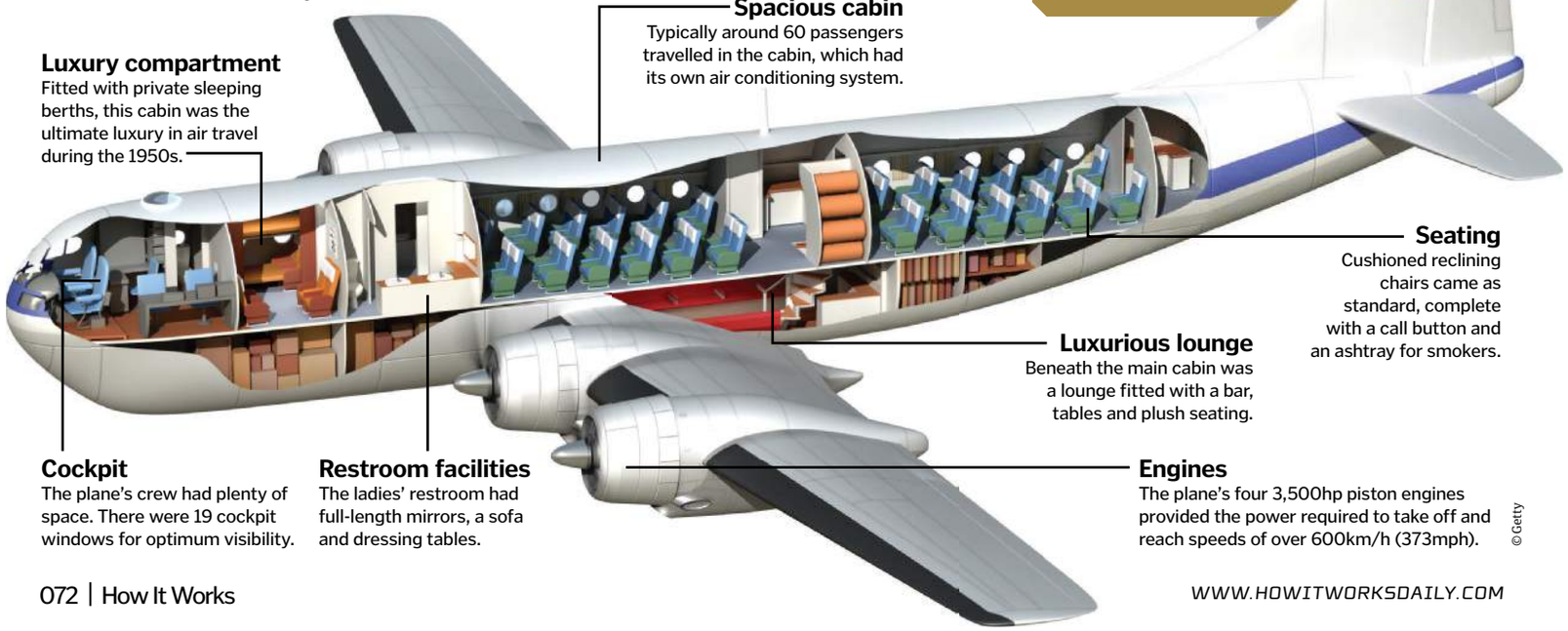
Commercial flights in the 1950s were still a luxury; only the wealthy were able to fly regularly for business and pleasure. In-flight freebies included cigars and evening robes – a far cry from the packet of peanuts you might receive on board today. Passengers often drank and smoke for the duration of the flight, reclining their seat and stretching their legs in the roomy cabin.

The food was comparable to a five-star hotel, and often consisted of a decadent three-course feast, served on china and glass rather than plastic and polystyrene. If you fancied getting some shut-eye, you were able to sleep in comfortable bunk beds made up in advance by the stewardesses. Modern day airlines would struggle to provide the luxury that 1950s passengers were accustomed to; it really was the golden age of air travel.

It was common for passengers to relax on sofas and sip champagne during their flight

Post-war air travel

See inside Boeing's first transatlantic commercial plane



Luxury compartment
Fitted with private sleeping berths, this cabin was the ultimate luxury in air travel during the 1950s.

Spacious cabin
Typically around 60 passengers travelled in the cabin, which had its own air conditioning system.

Seating
Cushioned reclining chairs came as standard, complete with a call button and an ashtray for smokers.

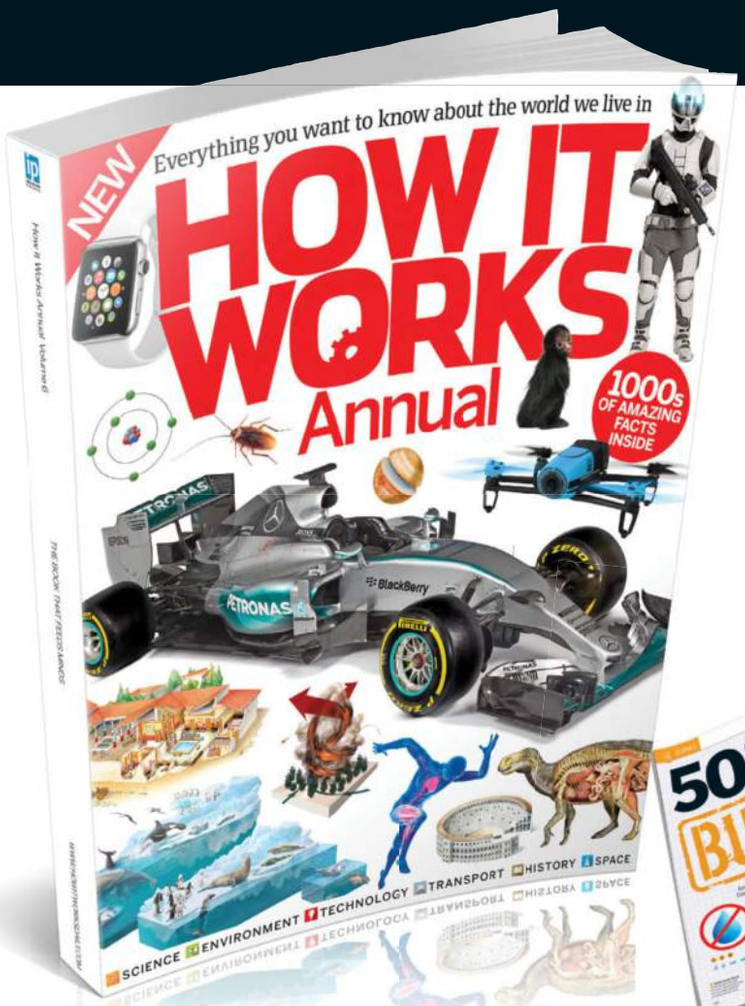
Luxurious lounge
Beneath the main cabin was a lounge fitted with a bar, tables and plush seating.

Cockpit
The plane's crew had plenty of space. There were 19 cockpit windows for optimum visibility.

Restroom facilities
The ladies' restroom had full-length mirrors, a sofa and dressing tables.

Engines
The plane's four 3,500hp piston engines provided the power required to take off and reach speeds of over 600km/h (373mph).

From the makers of HOW IT WORKS



HOW IT WORKS Annual

From the science behind love, to the latest technology trends, the How It Works Annual is a collection of the best content from the last year including over 1,000 facts about everything from ice skating to the life of a dinosaur.

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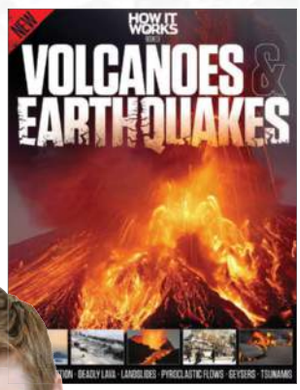

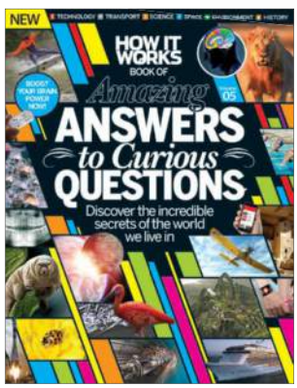

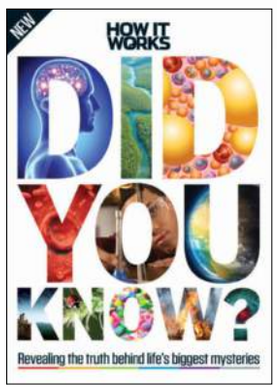

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Nintendo's VR headset

Looking back on the first commercial virtual reality headset, 20 years later

Upon Virtual Boy's release in 1995, Nintendo promised the first portable video game console capable of displaying true 3D graphics. To create a 3D image, Nintendo opted for a goggle-like headset that displayed a different image to each eye. Either side of the headset featured a vertical line of LEDs, which would project a strip of the game screen through a lens onto an oscillating mirror. The image would be reflected toward the right or left eye depending on the position of the mirror, which would switch back and forth 50 times per second. This oscillation was fast enough to trick the brain into thinking it was seeing a full 3D scene of the game.

The resulting image is only possible due to a visual phenomenon known as parallax, which is the apparent change in position of an object relative to its background. As we have two eyes that are spaced a small distance apart, we see the world from two different angles. The left and right eyes send simultaneous signals to the brain, providing slightly different versions of the same image. The brain then interprets these two signals to produce a single 3D image, allowing us to assess depth and estimate how far away objects are. Nintendo relied on this principal to provide a 3D effect for its gamers, without having to spend millions on a more realistic system that they'd have struggled to miniaturise.

In spite of its many limitations, the Virtual Boy displayed some revolutionary technology for its time, some of which both Oculus Rift and Sony's Project Morpheus have returned to, more than two decades later.

Controller
Its dual D-pads not only helped left-handers, but also provided a full range of motion in a 3D virtual world.

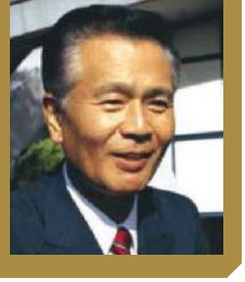
Power
The Virtual Boy was powered by six AA batteries, which were all housed in the back of the controller.

Screen
The screen displayed only black and three shades of red at a resolution of 384 x 224 pixels.

> *"Nintendo promised the first portable video games console capable of displaying true 3D graphics"*

Games
Only 22 games were ever released for the Virtual Boy, including *3D Tetris* and *Mario's Tennis*.

Nintendo's pioneering designer



From machine maintenance man to Game Boy mastermind, Gunpei Yokoi became one of Nintendo's most famous developers. His big break came when company president Hiroshi Yamauchi stumbled across a toy he'd made – an extending arm that could grab out of reach objects. Amazed, Yamauchi ordered Yokoi to develop it into a sellable product in time for Christmas. It was a success and over the next 20 years, Yokoi worked on the *Donkey Kong* and *Mario* franchises, before inventing the Game Boy. He went on to design the Virtual Boy, which he hoped would enhance Nintendo's reputation as an innovator, and showcase technology that its competitors couldn't replicate. This was his one and only commercial failure, but people close to him have commented that he was rushed into releasing a version he wasn't happy with. His life was sadly cut short by a car accident, but his Nintendo legacy will live on forever.

Eye shield
The neoprene eye shield was designed for comfort, and helped immerse players in the game.

Adjustable
Players could modify the distance between the right and left screens to match the distance between their eyes.

The statistics...

Virtual Boy

Weight: 760g (26.8oz)

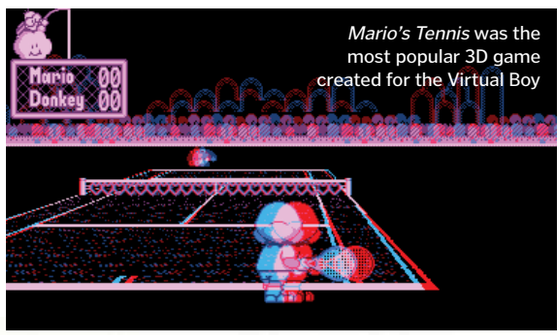
Price on release: $179.95 (approx £180/$280 today)

Best selling game: *Mario's Tennis*

Processor: NEC V810

Sound: 16-bit stereo

Power supply: Six AA batteries



Mario's Tennis was the most popular 3D game created for the Virtual Boy

Motherboard
This was responsible for loading game cartridge data and driving the LED displays, as well as sending audio data to the speaker.

The Virtual Boy was designed to be used at a table, but Nintendo originally promised to release a harness so that players could stand

The Game Boy was undoubtedly Yokoi's greatest creation, and quickly became a household favourite

Audio
Each side had a built-in speaker, providing 16-bit stereo sound to each ear.

Mount Everest: the first climb

A death-defying mission to conquer the world's highest mountain

With just enough room for them to stand side by side, Edmund Hillary and Sherpa Tenzing Norgay looked out at a view no one else had ever seen before. It was 11:30am on 29 May 1953 and they had just become the first people to ever reach the summit of Mount Everest.

Their journey began over two months before, when a team of 14 expedition members, led by British Army Colonel John Hunt, set off for Base Camp accompanied by 20 Sherpa guides and over 350 porters carrying thousands of kilograms of equipment. To complete the climb, the team established many camps along their route, some of which are still used by climbers today, and used special breathing apparatus to survive the thin air at high altitudes.

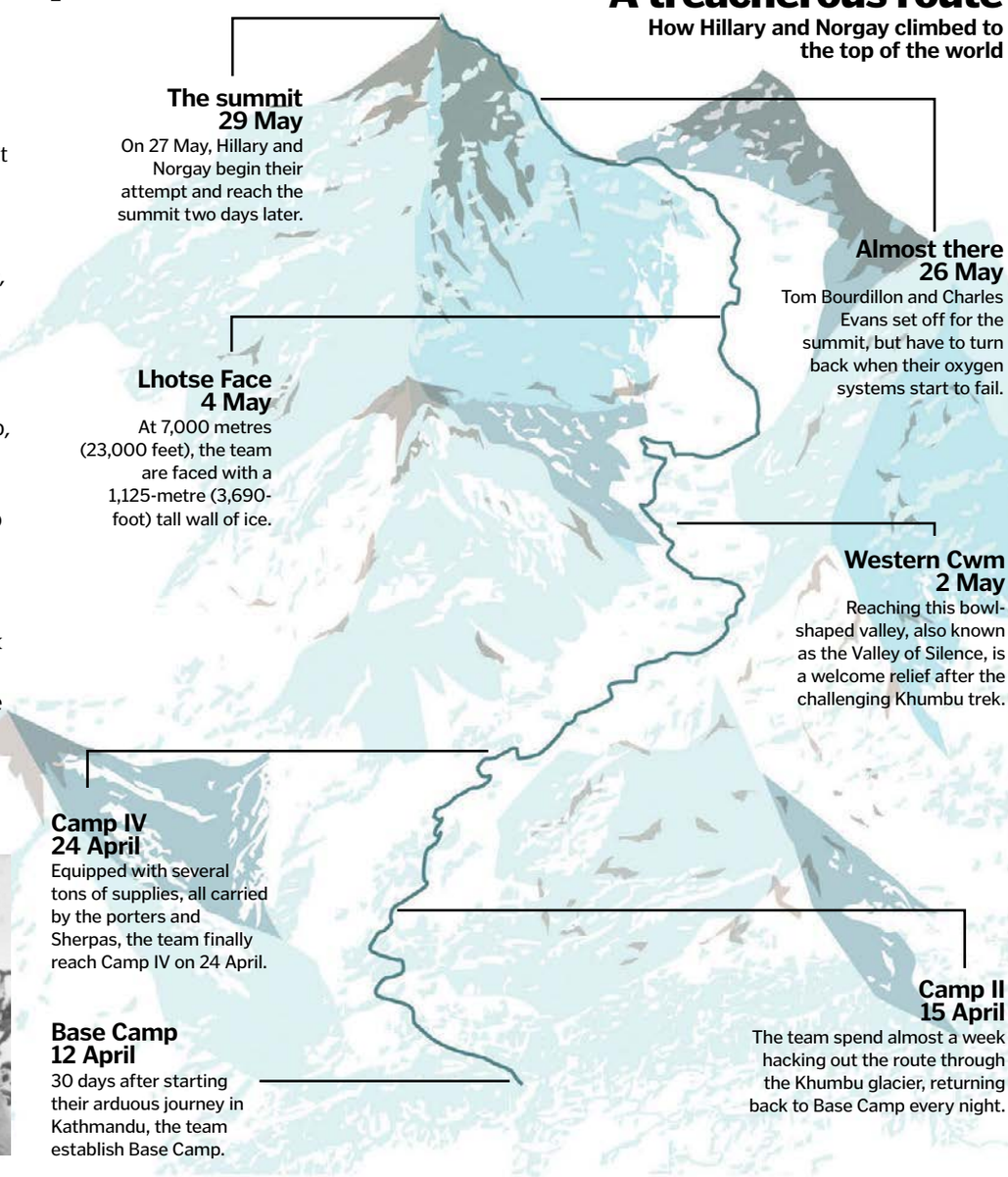
Along their journey, they had to scale glaciers, carve out paths in the ice and cross dizzying crevasses, and many had to turn back when their oxygen supplies depleted.

Eventually, Hillary and Norgay made it to the top, where they hugged with relief, planted flags and took some photos. They began their journey back down the mountain soon after to avoid running out of oxygen.

Edmund Hillary (left) and Sherpa Tenzing Norgay (right) on their journey to the top of Everest

A treacherous route

How Hillary and Norgay climbed to the top of the world



The summit
29 May
On 27 May, Hillary and Norgay begin their attempt and reach the summit two days later.

Almost there
26 May
Tom Bourdillon and Charles Evans set off for the summit, but have to turn back when their oxygen systems start to fail.

Lhotse Face
4 May
At 7,000 metres (23,000 feet), the team are faced with a 1,125-metre (3,690-foot) tall wall of ice.

Western Cwm
2 May
Reaching this bowl-shaped valley, also known as the Valley of Silence, is a welcome relief after the challenging Khumbu trek.

Camp IV
24 April
Equipped with several tons of supplies, all carried by the porters and Sherpas, the team finally reach Camp IV on 24 April.

Camp II
15 April
The team spend almost a week hacking out the route through the Khumbu glacier, returning back to Base Camp every night.

Base Camp
12 April
30 days after starting their arduous journey in Kathmandu, the team establish Base Camp.

How to celebrate Day of the Dead

Discover the Mexican tradition for honouring the dead

Every year on the first two days of November, Mexican towns and cities are alive with colourful celebrations. A tradition that has developed from rituals dating back some 3,000 years, Día de Muertos (Day of the Dead) is a chance for people to remember and honour their deceased loved ones. Instead of mourning them with sadness, elaborate parties and parades are held to celebrate their lives with dancing, costumes and delicious feasts. Graves are decorated with flowers and candles, and altars are laden with offerings of food and drink for those that have passed away. Skulls, or calaveras, are the traditional symbol of the celebration and are typically depicted on masks or sweets that are eaten or given as gifts.

Although it is a Mexican tradition, Day of the Dead is also celebrated throughout Latin America and in parts of the United States. The festivities are split across two days, with 1 November as Día de los Inocentes – a day to remember children who have passed away – and 2 November for remembering deceased adult relatives.

People often paint their faces with elaborate skull designs for Day of the Dead celebrations

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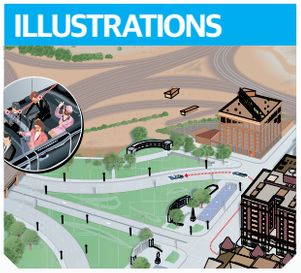

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How far can we see into space?

Find out how astronomers calculate the distances to far-away galaxies

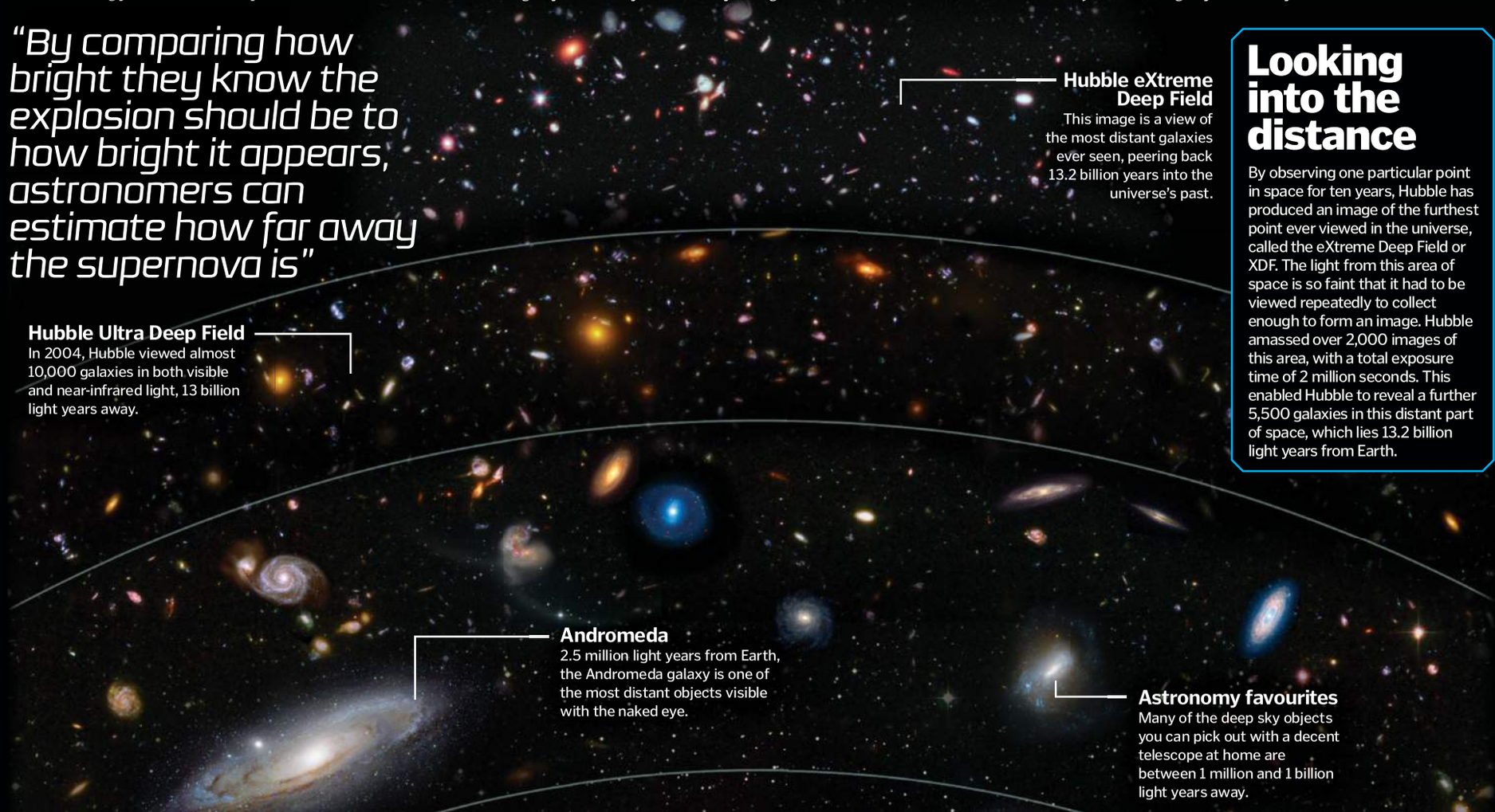
Using the naked eye, it's possible to spot the Andromeda galaxy, around 2.5 million light years from Earth. It has been visible to mankind long before we even knew it was another galaxy, but scientists are now determined to explore beyond the realms of nearby galaxies into the vast expanse of the universe.

During its 25 years of service, the Hubble Space Telescope has provided an incredible amount of data, helping astronomers see further than ever before. Among its most famous contributions are the Hubble Deep Field images, which have provided us with the most detailed glimpses into the farthest reaches of the visible universe.

Calculating just how far away Hubble's most distant discoveries are from Earth is challenging, but astronomers have found a way to do this accurately. They measure the brightness of Type Ia supernovas – where a white dwarf feeds on its binary partner star until it detonates. As astronomers know these stars always explode when they reach a specific mass (1.4 times that of our Sun), the resultant supernova should always be a particular brightness. By comparing how bright they know the explosion should be to how bright it appears to be, astronomers can estimate how far away the supernova (and therefore its parent galaxy) is from us.

This system works well for galaxies up to around 3 billion light years away, but for anything further, astronomers use the Hubble Constant. Edwin Hubble discovered that the universe is constantly expanding in all directions, which means the further away you look, the faster the galaxies are moving away from Earth. This produces a phenomenon known as redshift, whereby light shifts to the red end of the spectrum as its wavelength is stretched. By measuring redshift, you can estimate how fast an object is moving, and thus its approximate distance from Earth. Thanks to this clever piece of physics, astronomers can calculate reasonable estimates to the outer reaches of the observable universe. For example, the galaxies in Hubble's farthest Deep Field image, called the 'eXtreme Deep Field', are around 13.2 billion light years away.

"By comparing how bright they know the explosion should be to how bright it appears, astronomers can estimate how far away the supernova is"



Hubble eXtreme Deep Field
This image is a view of the most distant galaxies ever seen, peering back 13.2 billion years into the universe's past.

Hubble Ultra Deep Field
In 2004, Hubble viewed almost 10,000 galaxies in both visible and near-infrared light, 13 billion light years away.

Andromeda
2.5 million light years from Earth, the Andromeda galaxy is one of the most distant objects visible with the naked eye.

Astronomy favourites
Many of the deep sky objects you can pick out with a decent telescope at home are between 1 million and 1 billion light years away.

Looking into the distance

By observing one particular point in space for ten years, Hubble has produced an image of the furthest point ever viewed in the universe, called the eXtreme Deep Field or XDF. The light from this area of space is so faint that it had to be viewed repeatedly to collect enough to form an image. Hubble amassed over 2,000 images of this area, with a total exposure time of 2 million seconds. This enabled Hubble to reveal a further 5,500 galaxies in this distant part of space, which lies 13.2 billion light years from Earth.

Centre of the galaxy
Our Solar System is about 26,000 light years away from the middle of the Milky Way.

Horsehead Nebula
Discovered in 1888 by Scottish astronomer Williamina Fleming, the Horsehead Nebula lies approximately 1,500 light years from Earth.

Crab Nebula
The Crab Nebula is the result of a supernova, and lies roughly 6,500 light years from Earth.

Pleiades
Dominated by hot blue stars, this open star cluster can be found in the constellation of Taurus, roughly 444 light years from Earth.

Alpha Centauri
The nearest star system to our own, Alpha Centauri, is just over four light years away, and contains the closest exoplanet to Earth.

What can we see?

Find out what we've been able to observe so far, and where these mysterious objects lie relative to Earth

The James Webb Space Telescope

When the James Webb Space Telescope (JWST) launches in 2018, it will be tasked with studying each phase in the history of the universe, aiming to find the first galaxies to form after the Big Bang and determine how they came to exist.

The JWST's most striking feature is a layered sunshield that will work to reduce the Sun's heat in order to protect the instruments on board. This tennis court-sized sunshield splits the telescope into two sections. The warm side is equipped with solar panels, communication devices, and steering, while the cold side houses the telescope itself and other scientific instruments, which all need to operate at temperatures below -223 degrees Celsius (-370 degrees Fahrenheit).

This is because the JWST will be trying to observe faint infrared light from exceptionally far away objects in the eXtreme Deep Field, and must avoid swamping the sensitive instruments with excess infrared radiation from the Sun.

If all goes to plan, the JWST will detect the faint light from these distant targets, allowing us to see even further than Hubble, to when the universe was in its infancy 13.5 billion years ago.

The JWST is designed to examine the early universe in more detail

DID YOU KNOW? *Hubble's eXtreme Deep Field was created by focussing on a seemingly empty spot in the Ultra-Deep Field*

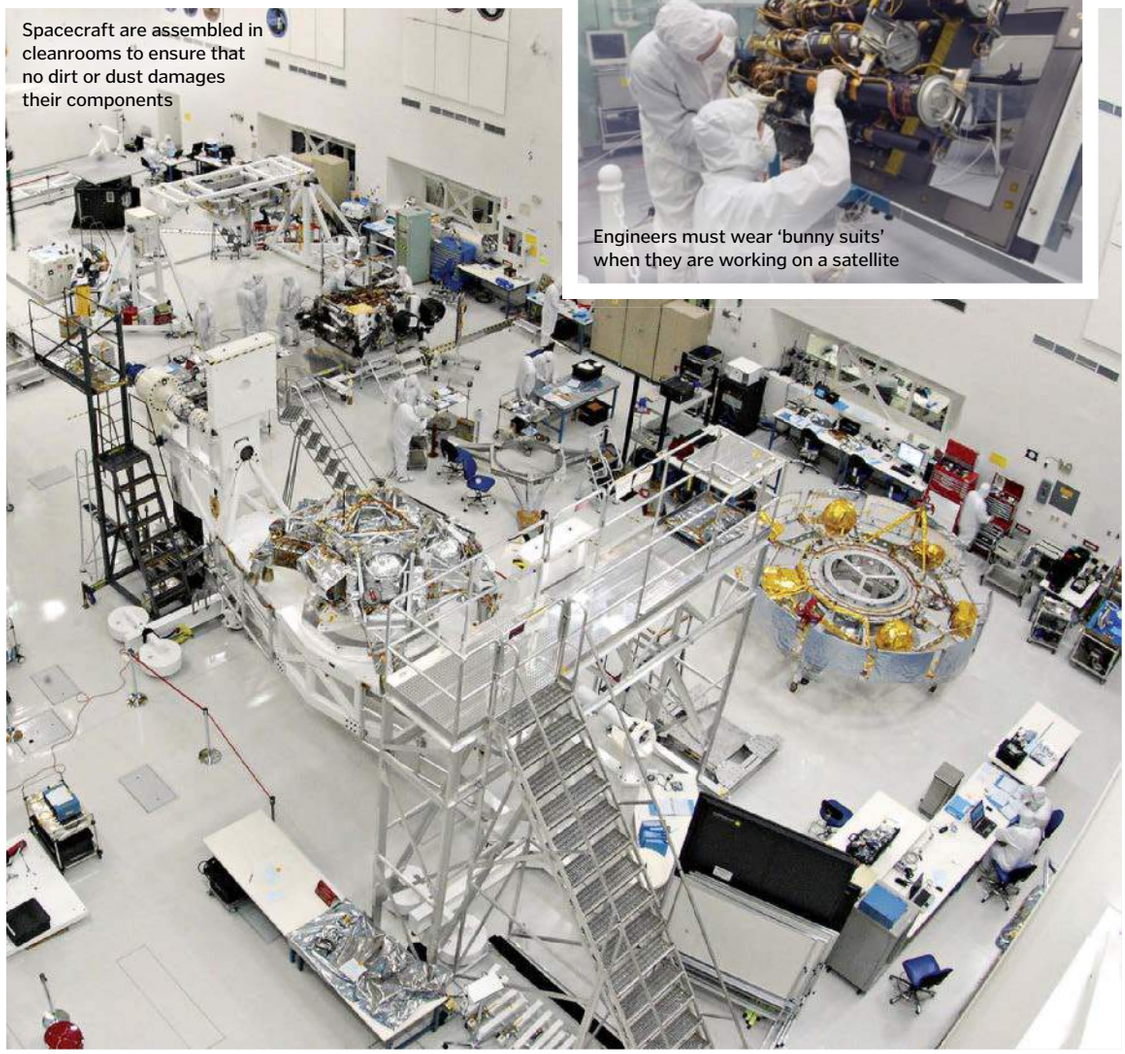
Spacecraft assembly rooms

Why probes must be built in super-clean environments

You can head to the nearest operating theatre or clean your kitchen from top to bottom, but you'll never find anywhere as squeaky clean as the quarters where spacecraft are built. Not too surprisingly, they are known as cleanrooms.

Think of your favourite spacecraft – whether it's the Cassini probe which travelled to Saturn or the Rosetta mission that swung into orbit around Comet 67P, you'll find that it was assembled in a cleanroom before it was launched. The reason for this is that even the tiniest speck of dirt could cause an electrical circuit to fail or, if dust settles on a spacecraft's mirrors or lenses, then the spacecraft could 'go blind'. The water content in the air is also kept fairly low by maintaining temperatures at around 20 degrees Celsius (68 degrees Fahrenheit).

For cleanrooms to remain contaminant-free, the air must be filtered and everyone entering the area must walk across a sticky floor mat to remove any dirt from their shoes. They must also wear a sterile 'bunny suit' that fits snugly around their head and feet, as well as gloves and a face mask.



Spacecraft are assembled in cleanrooms to ensure that no dirt or dust damages their components

Engineers must wear 'bunny suits' when they are working on a satellite

Blue skies on Pluto

NASA's New Horizons spacecraft reveals atmospheric hazes

An azure blue halo around Pluto is the signature that this dwarf planet has an atmosphere, and that there are chemical reactions occurring there, too. We know that Pluto's atmosphere contains nitrogen and methane, but these would not turn the sky blue. When NASA's New Horizons space probe flew past Pluto on 14 July 2015, some of the amazing pictures that it took showed layers of atmospheric haze above the dwarf planet's surface. Pluto's atmosphere is not like Earth's; you couldn't breathe it and it is much less dense – the surface pressure on Pluto is three millionths of a bar, compared to Earth's one bar.

So why does it appear blue? New Horizons is showing us layers of haze around Pluto, full of nitrogen and methane molecules. Even though the Sun is far away, its ultraviolet light can break down these molecules, instigating chemical reactions that produce tholins, which are small, soot-like particles. These slowly sink to Pluto's surface and absorb red light, but scatter blue light, so we see Pluto's atmosphere as blue.

Pluto in silhouette as seen by New Horizons, with sunlight from behind the dwarf planet shining through the atmosphere

What are constellations?

Without making patterns, our night sky would be a confusion of stars

While we know that the stars are many light years away, and all at different distances, astronomers still put them into groupings called constellations. These are named after the characters, animals and objects they resemble – some of which are from the pages of mythology.

The constellations help us make sense of the night sky. Without them, it would be a chaotic sprinkling of stars. We could still use celestial coordinate systems – which are similar methods to how we use latitude and longitude on Earth – to locate objects in the night sky, but constellations give astronomers a quick and visual way of getting their bearings in the cosmos.

There are 88 official constellations (unofficial constellations, such as the Big Dipper, are called asterisms) and these provide the catalogue names of the stars. For example, Deneb is the brightest star in the constellation Cygnus, so this is known as Alpha Cygni. The brightest star in Boötes is Arcturus, so it is also called Alpha Boötis. The constellations also help us to locate deep sky objects. The Andromeda galaxy is in the constellation of Andromeda, so seasoned stargazers will know straight away the rough area of the sky in which to look.

The entire sky is mapped by constellations – there's not one bit of celestial real estate that isn't included. The modern constellation borders were drawn up in 1930 by the International Astronomical Union (IAU), and extend beyond the traditional star patterns to include the regions of space around them.

You'll probably have heard of the Zodiac constellations – Capricorn, Aquarius, Pisces and so on. They are plotted along the path that the Sun appears to move through each year. Your sign is the constellation that the Sun was in at the time of your birth.

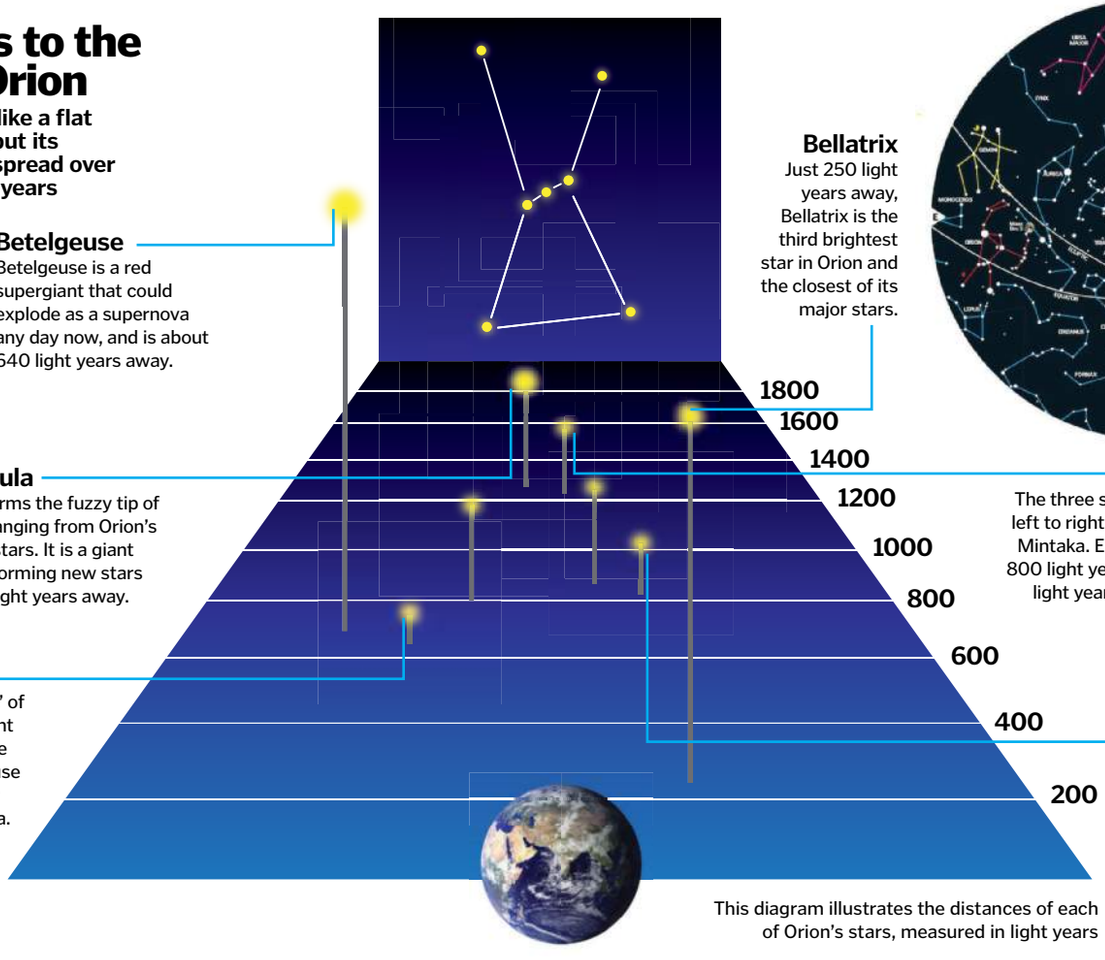
Origins of constellations

Civilisations going back to ancient times are thought to have charted the constellations. At first, these patterns of stars were used for astrological predictions and navigation, as well as for communication among astronomers. However, as the modern field of astronomy developed, it was soon discovered that different culturally nominated constellations made communication tricky. To solve the problem, the IAU divided the sky into 88 constellations between the Northern and Southern Hemisphere and gave them universally accepted names.

The constellation of Orion depicts a hunter from Greek mythology

Distances to the stars of Orion

Orion might look like a flat blanket of stars, but its components are spread over hundreds of light years



Betelgeuse
Betelgeuse is a red supergiant that could explode as a supernova any day now, and is about 640 light years away.

Bellatrix
Just 250 light years away, Bellatrix is the third brightest star in Orion and the closest of its major stars.

Orion nebula
The nebula forms the fuzzy tip of the 'sword' hanging from Orion's belt of three stars. It is a giant cloud of gas forming new stars and is 1,344 light years away.

Orion's Belt
The three stars in Orion's Belt, from left to right, are Alnitak, Alnilam and Mintaka. Estimates place Alnitak at 800 light years away, Mintaka 1,300 light years away and Alnilam 900 light years away.

Saiph
At the lower-left 'knee' of Orion, Saiph is 650 light years away. It is a large star that, like Betelgeuse and Rigel, will one day blow up in a supernova.

Rigel
The brightest star in Orion is Rigel, a white supergiant, about 860 light years away.

This diagram illustrates the distances of each of Orion's stars, measured in light years

‘Young Jupiter’ discovered

How a new exoplanet could reveal secrets of the Solar System

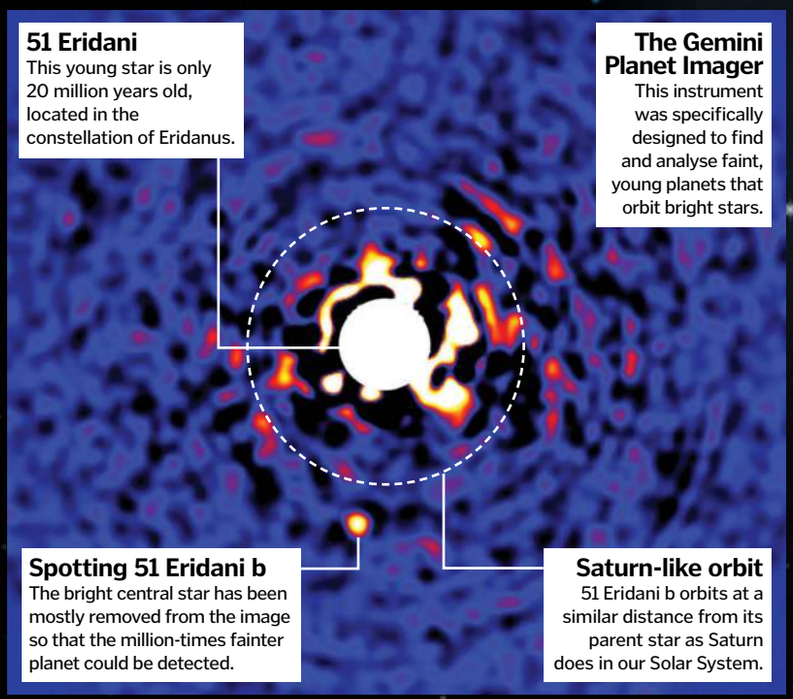
In a distant solar system 100 light years away, scientists have discovered an exoplanet that seems oddly familiar. 51 Eridani b is a gas giant roughly 11 times wider than Earth, and is similar to our Solar System’s very own Jupiter. However, the new discovery, made using the Gemini Planet Imager, is only 20 million years old – a blink of an eye compared to 4.5-billion-year-old Jupiter! With more tests, scientists could uncover how it came into existence and then that knowledge could be used to understand how Jupiter was formed.

Even at 427 degrees Celsius (800 degrees Fahrenheit), this so-called ‘young Jupiter’ is actually relatively cold and small compared to other gas giant exoplanet discoveries. This suggests that rather than material collapsing quickly to form a hot planet, 51 Eridani b’s core built up gradually. This slower growth process would mean its formation has more in common with Jupiter’s. Further investigation is needed to see whether 51 Eridani b can help us understand how the planets in our own Solar System came into being.

This artist’s impression of 51 Eridani b shows hot layers glowing through a cloudy atmosphere

Journey of discovery

How scientists spotted 51 Eridani b with the Gemini Planet Imager



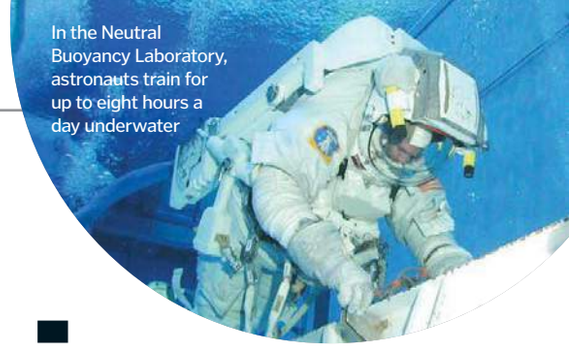
Principia mission launch

Ground control to Major Tim – what will Britain’s first official astronaut be doing on the ISS?

When Major Tim Peake blasts off into space on 15 December, he will be embarking on a six-month stay on the International Space Station. His mission is named Principia, after Isaac Newton’s famous *Naturalis Principia Mathematica*, which explained his theory of gravity.

While onboard the Space Station, Peake will have a 40-hour working week, conducting over 30 experiments for Principia, as well as research on behalf of scientists all over the world. Peake will be investigating how living in space affects the body and mind. Other experiments will include using software to drive a robotic rover on the ground from space, and examining how metals behave when they are heated and rapidly cooled in microgravity. He has been trained to fix just about anything on the ISS and to go on space walks in case of emergencies. Peake will return to Earth in May 2016.

Tim Peake’s Principia experiments will further our understanding of the effects of space travel



In the Neutral Buoyancy Laboratory, astronauts train for up to eight hours a day underwater

Underwater astronaut training

The best place on Earth to prepare for zero gravity is a swimming pool

When an astronaut prepares for a mission to the International Space Station, they must practise the tasks that they'll be carrying out in space. However, in order to make the training as realistic as possible, the microgravity they'll encounter outside our planet's atmosphere needs to be mimicked here on Earth.

It may sound far-fetched, but NASA has an ingenious way of replicating space's unique environment on our home planet – it has placed a large-scale mock-up of the International Space Station in an enormous swimming pool. The American space agency calls this 12-metre (40-foot) deep pool the Neutral Buoyancy Lab (NBL) and astronauts have been training here since 1996.

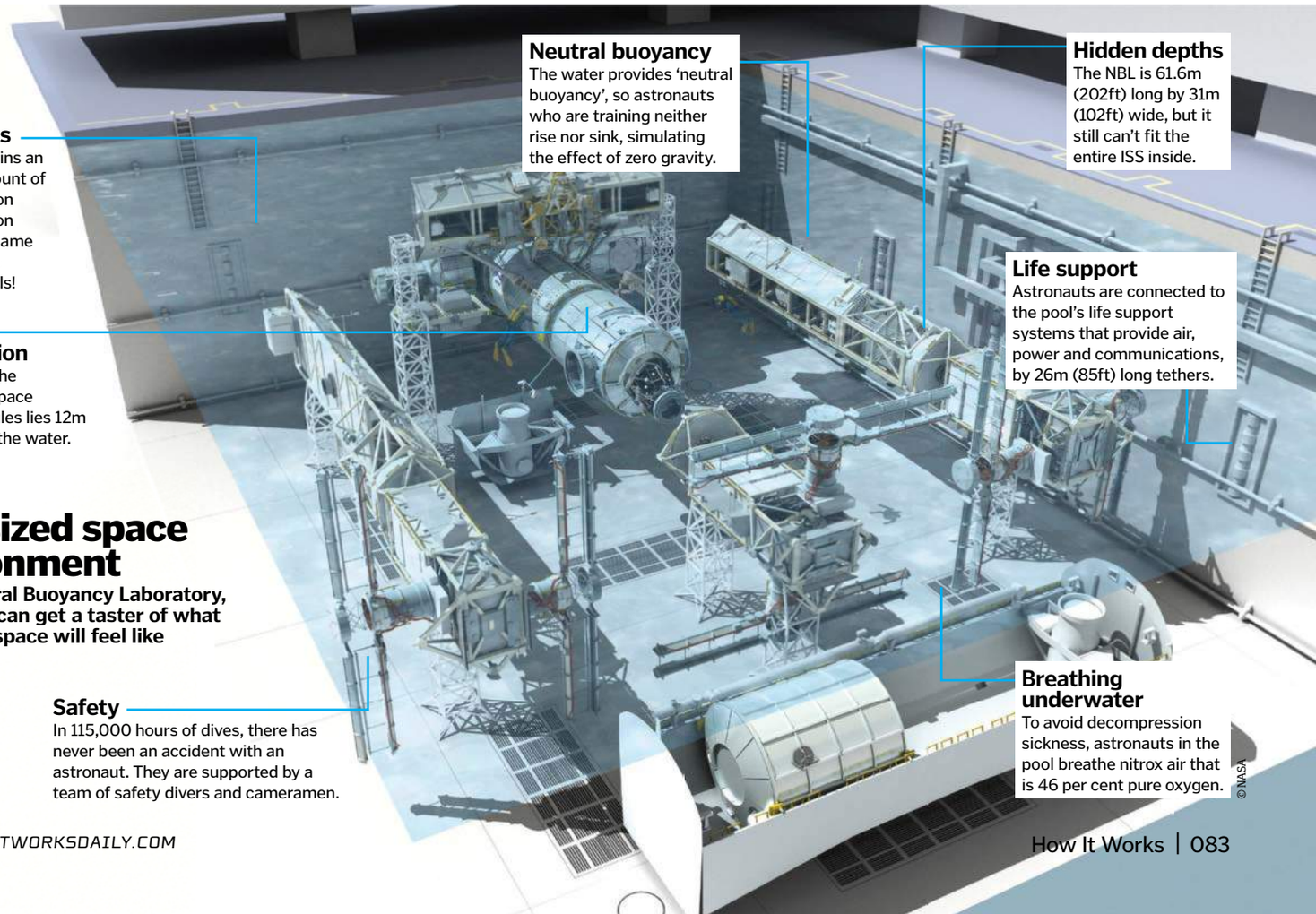
Astronauts undertake six-to-eight-hour underwater sessions on a daily basis – the equivalent time for an Extravehicular Activity session in space. When it's time to begin training, a camera diver shadows the astronaut to capture everything that happens, so it can be reviewed later. Safety divers are also on-hand at all times and the astronaut is rigged up to various support systems for air, power and communications.

Underwater, the trainee astronaut is breathing nitrox air, which is comprised of 46 per cent oxygen rather than the normal 21 per cent we breathe every day. This increased oxygen concentration reduces the risk of decompression sickness. Long tethers also enable an astronaut to lock themselves onto handrails while they are practising a task. Everything they do underwater is a simulation of what they'll be doing onboard the International Space Station.

Size does matter

Before getting in the water for a session in the Neutral Buoyancy Laboratory, an astronaut has to dress for the part. During the fitting for their space suit, there are 36 measurements taken of their bodies and 46 measurements of their hands, while plenty of padding inside the suit ensures they don't slip around. The end result is so heavy – weighing almost as much as two men – that several technicians are required to help the astronaut get suited and booted.

European Space Agency astronaut Samantha Cristoforetti, flight engineer of Expedition 42/43, prepares to be submerged in the waters of the NBL



Voluminous
The pool contains an enormous amount of water: 28 million litres (6.2 million gallons) – the same as ten Olympic swimming pools!

Sunken space station
A mock-up of the International Space Station's modules lies 12m (40ft) deep in the water.

Neutral buoyancy
The water provides 'neutral buoyancy', so astronauts who are training neither rise nor sink, simulating the effect of zero gravity.

Hidden depths
The NBL is 61.6m (202ft) long by 31m (102ft) wide, but it still can't fit the entire ISS inside.

Life support
Astronauts are connected to the pool's life support systems that provide air, power and communications, by 26m (85ft) long tethers.

Safety
In 115,000 hours of dives, there has never been an accident with an astronaut. They are supported by a team of safety divers and cameramen.

Breathing underwater
To avoid decompression sickness, astronauts in the pool breathe nitrox air that is 46 per cent pure oxygen.

© NASA

Pool-sized space environment

In the Neutral Buoyancy Laboratory, astronauts can get a taster of what working in space will feel like

BRAIN DUMP

Because enquiring minds need to know...

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MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon

Luis has a degree in zoology from Oxford and another in real-time computing. He builds steampunk gizmos and electronic gadgets, and his articles about science, tech and nature have been published around the world.

Laura Mears

Laura studied biomedical science at King's College London and has a master's from Cambridge. She escaped the lab to pursue a career in science communication and also develops educational video games.

Alexandra Cheung

Having earned degrees from the University of Nottingham and Imperial College London, Alex has worked at many prestigious institutions, including CERN, London's Science Museum and the Institute of Physics.

Ella Carter

Fascinated by the underwater realm, Ella studied marine biology and oceanography at university before embarking upon a career in publishing. She adores the natural world and loves researching and writing about the wonders within.

Sarah Bankes

Sarah has a degree in English and has been a writer and editor for more than a decade. Fascinated by the world in which we live, she enjoys writing about anything from science and technology to history and nature.

Parrots are so good at mimicking that one lost bird in Japan could recite his address

Why do parrots copy what we say?

Ashwin Taggart

Parrots, along with other bird species, are able to learn and mimic sounds. In the wild, different species of parrot can use this to mimic other bird species or communicate with their own. This can lead to local 'dialects' developing, and could also be a means of mate selection, as males try to impress females with their ability to learn and produce new sounds.

The attractiveness of parrots as pets is due to their ability to make much lower tones, which can sound a lot like the human voice. Parrots copy certain words and phrases that we say repeatedly, as they interpret this as a local 'call'. In the same way that a parrot would adopt and mimic a specific squawk from another bird in the wild, if you call it 'pretty Polly' consistently, it will learn it as a call of its local flock, and begin to join in. **EC**

Purple-leaved plants still contain chlorophyll, but have a higher concentration of another coloured pigment, anthocyanin

How do purple-leaved plants photosynthesise?

Joseph Newell

Most of us will remember from biology lessons at school that the process of photosynthesis (whereby plants absorb energy from light) requires the green pigment in leaves known as chlorophyll. So how do purple-leaved plants carry out this process?

All plant leaves contain three primary classes of pigments: chlorophyll, carotinoids and anthocyanins. So, whereas green-leaved plants have a high concentration of chlorophyll, purple-leaved plants have a higher concentration of anthocyanin. And since anthocyanins absorb blue, blue-green and green light, and reflect reds and purples, their leaves appear red or purple to the human eye. So, chlorophyll is still present in purple-leaved plants, but hidden by a higher concentration of anthocyanins. **SB**

Champagne flutes have a smaller surface area to help the drink stay bubbly

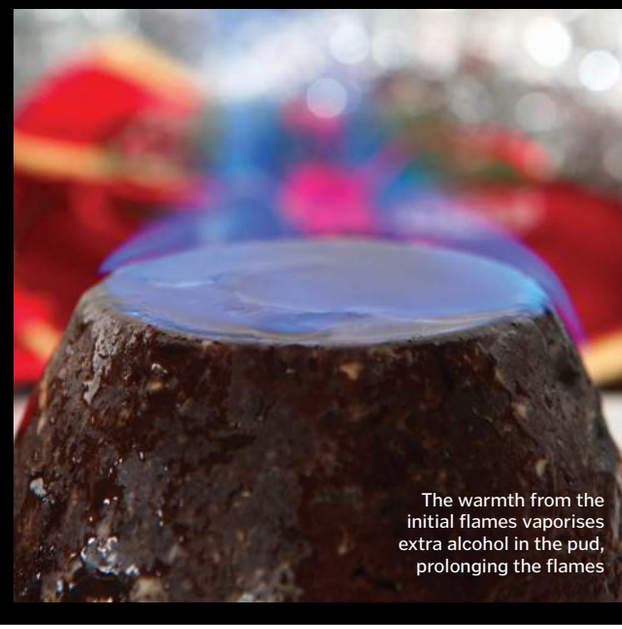
Why are champagne and wine glasses different shapes?

Aaron Whistler

Champagne was originally a drink that you knocked back in one gulp, like a tequila shot. In around 1663, British glass blowers designed the wide, shallow 'coupe' glass specifically for champagne to make it easy to swig like this. In the 1950s, the tall, thin 'flute' became more popular because the smaller surface area of the opening helps stop the champagne going flat so fast. For wine, a larger glass has more room at the top for the volatile aroma compounds to collect and the tapered rim helps hold them there. Some wine experts now prefer this glass shape for champagne as well. **LV**

Why doesn't a flaming Christmas pudding burn?

To create this quintessential Christmas centrepiece, just before serving the recipe will tell you to heat up an alcoholic spirit, such as brandy. You then pour it all over the prized pud, and proceed to the table to start the show. When set alight, it's the vapour from the alcohol that burns (this was released when you warmed the spirit moments before lighting it). The pudding never actually catches fire and so doesn't burn at all. The flames go out when all the alcohol is vaporised, leaving nothing but a tasty, perfectly cooked festive dessert behind. Pass the brandy butter? **EC**



The warmth from the initial flames vaporises extra alcohol in the pud, prolonging the flames

With no air resistance, a bullet might travel through space forever

What would happen if you fired a gun in space?

The absence of air resistance and gravity would make a speeding bullet travel very differently in space. Although there would be no oxygen, bullets contain their own oxidiser, which would allow the gunpowder to ignite and fire the gun. With no air to slow it down, a bullet could in theory travel forever through deep space, although its path would be curved by the gravitational fields of large planets or other bodies. Floating freely in space, the recoil from the gun would also spin you in the opposite direction, a motion that would be harder to control without gravity holding you in place. **AC**

Are figs really full of baby wasps?

Christopher Newman

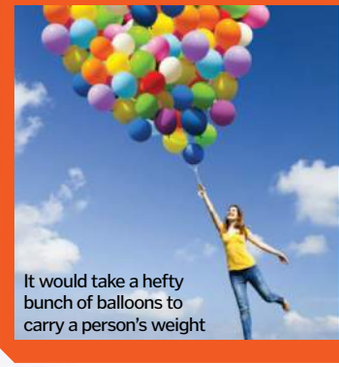
Figs do indeed contain the digested remains of dead wasps. It sounds disgusting, but these little insects are essential to the fig's life cycle. The fig is unable to reproduce without them, because most pollinating insects cannot reach the pollen in its inverted flower. The fig wasp is the fig's only pollinator, having found a way to wiggle inside. In return, the plant provides the wasp with a suitable environment for it to feed and grow its larvae. This process of mutualism means that the plant and wasp depend on each other for survival. However, once the wasp has laid her eggs, she is unable to exit the fig because the narrow passage through which she entered has torn off her wings and antennas. The wasp inevitably dies and an enzyme in the fig eventually breaks it down into protein. The eggs go on to hatch to reveal male and female wasps, which mate and then tunnel out, pollen in tow. **SB**

Figs do contain dead wasps, but they are broken down into protein, so you can't taste them!

FASCINATING FACTS

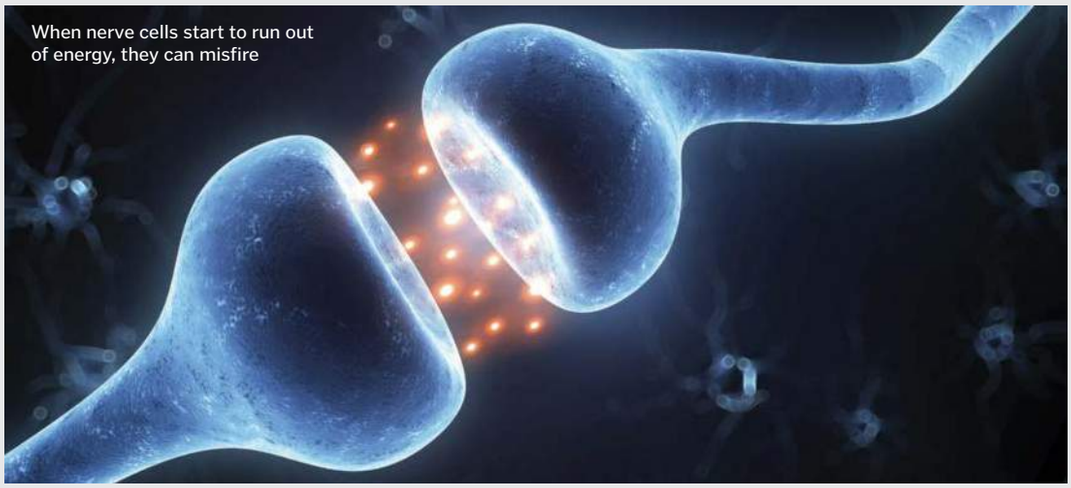
How many balloons would it take to lift you off the ground?

According to the University of Hawaii, you would need around 73,000 litres of helium to lift 75kg (164lb) – around the weight of an average man. That would fill about 600 party balloons! **LM**



It would take a hefty bunch of balloons to carry a person's weight

BRAIN DUMP



When nerve cells start to run out of energy, they can misfire

What causes pins and needles?

Cameron McClymont

Pins and needles is a type of 'paraesthesia' – a word which comes from the Latin for 'abnormal sensation'. It tends to happen when the blood supply to a nerve is temporarily reduced, like when you sit with your legs crossed for too long, or when a nerve is squashed.

Nerve cells are constantly pinging signals around the body, and each time they pass a signal on they need to reset before the next one comes.

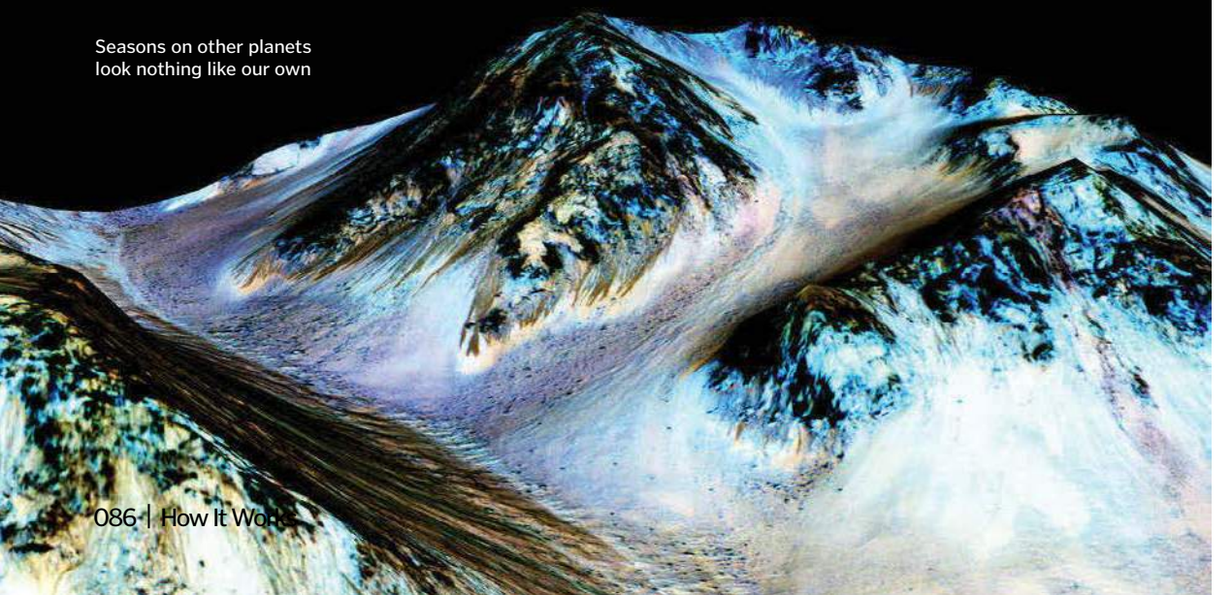
When nerve cells are starved of blood they cannot reset properly, so they just fire when they can, sending irregular messages onwards towards the brain. The disruption also affects the nerve cells waiting for their signals further down the line, which can start to fire off without warning.

The reason it feels like pins and needles is that the first nerve fibres to stop working are the smallest ones – the ones responsible for pain. **LM**

Do other planets have seasons like Earth?

Dave Gamble

Other planets experience seasons, although these typically look nothing like our planet's. Our seasons are caused by the 23-degree tilt in Earth's axis of rotation, exposing its hemispheres to different amounts of sunlight. Planets with a very slight tilt, such as Jupiter, have very small variations across the year. At the other extreme, with an 82-degree tilt, Uranus's hemispheres lean away from the Sun for decades at a time before swapping over. When spring comes after each 20-year winter, huge storms are triggered in its atmosphere. Other planets also experience differences due to the size and shape of their orbits (orbital eccentricity). A shorter orbit, such as Venus's, results in a much shorter year and shorter seasons. Unlike Earth, which has an almost circular orbit, Mars is ten per cent closer to the Sun during its northern hemisphere's winter than summer, giving rise to differences in the seasons undergone by either hemisphere. **AC**



Seasons on other planets look nothing like our own

FASCINATING FACTS

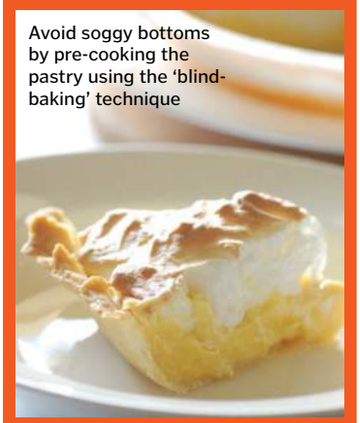
How many types of black hole are there?

Three types of black hole exist, distinguished by their mass: supermassive, stellar, and miniature. Miniature black holes have never been observed but scientists believe that they formed in the early days of our universe. **AC**

Stellar black holes result from the collapse of a star

Why do pies get a soggy bottom?

As a piecrust cooks, if the gluten fails to form a network before the fat in the recipe melts, the base won't be able to crisp up. Juicy fillings can also be the culprits! **EC**

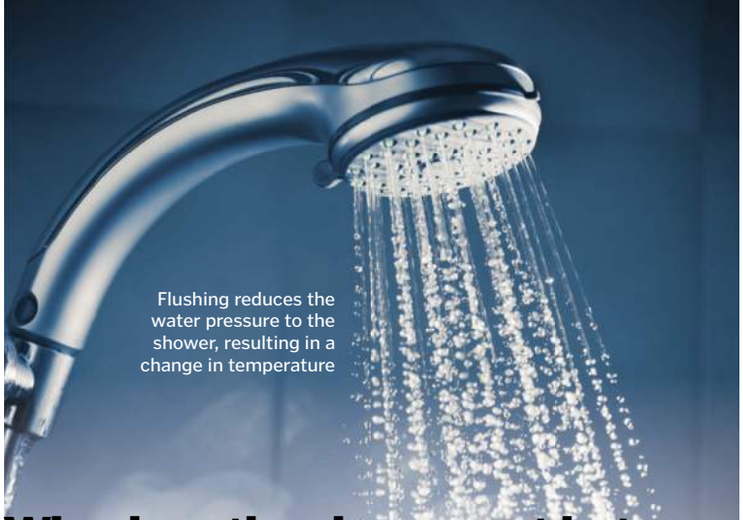


Avoid soggy bottoms by pre-cooking the pastry using the 'blind-baking' technique

What's the difference between a boat and a ship?

It's an arbitrary distinction but ships are generally larger. The cut-off can be anywhere from 40 to 500 tons, depending on which authority you consult, but fishing vessels are always boats. **LV**

Submarines are always boats, even though Royal Navy submarines are called HMS – Her Majesty's Ship.



Flushing reduces the water pressure to the shower, resulting in a change in temperature

Why does the shower get hot when someone flushes the toilet?

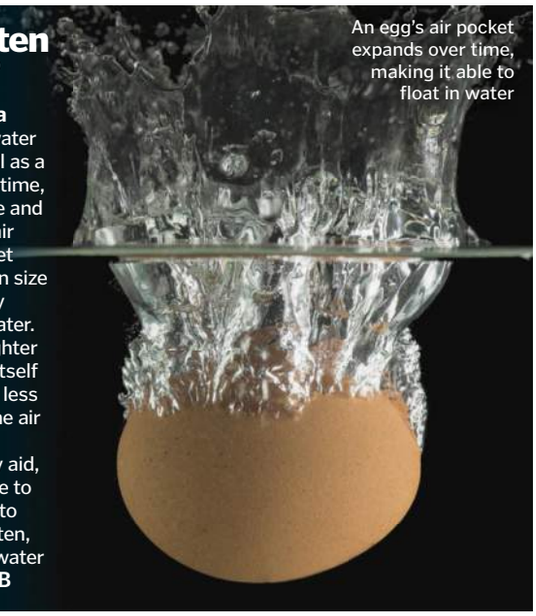
Bronte Rodgers

As soon as the toilet flushes, the cistern begins refilling from the cold water supply. That causes a drop in the water pressure to every cold water tap in the house, including your shower, so the water comes out more slowly. Electric showers work by passing cold water over a heating element and the slower the water flows, the more time it spends next to the element, and the hotter it gets. If your shower is fed from a hot water tank instead, the lower cold water pressure reduces the amount mixing with the hot water, so your shower still gets hotter. **LV**

Why do rotten eggs float?

Paula Morambuena

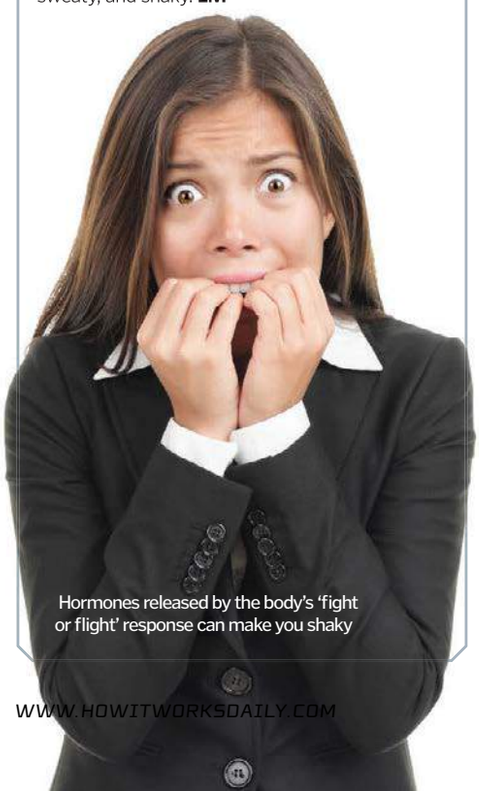
All eggs contain water in their shells, as well as a tiny air pocket. Over time, as an egg ages, more and more air enters the air pocket. The air pocket gradually increases in size until it has eventually replaced all of the water. Since gas is much lighter than water, the egg itself becomes lighter and less dense than water. The air pocket is effectively acting as a buoyancy aid, and so the egg is able to float. So if you want to know if an egg is rotten, place it in a bowl of water and see if it floats. **SB**



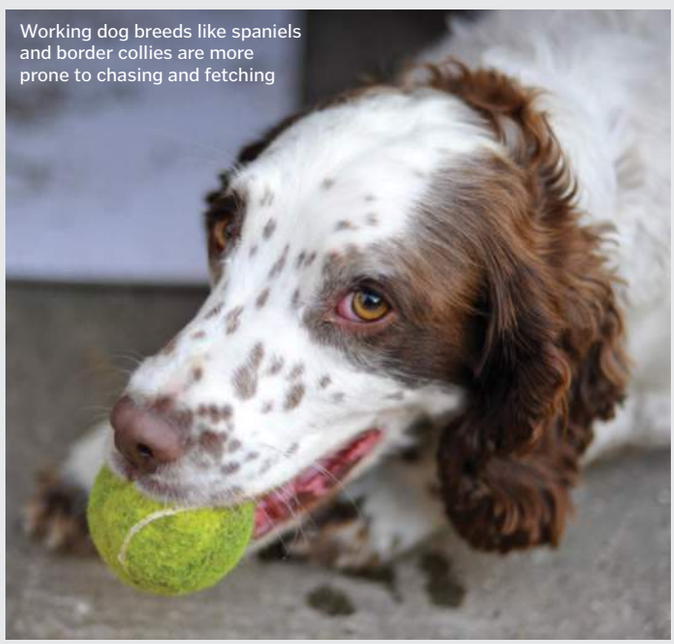
An egg's air pocket expands over time, making it able to float in water

Why do you shake when you're nervous?

Nervousness, anxiety and fear can trigger a biological coping mechanism known as the 'fight or flight' response. The response is driven by two main chemicals – adrenaline and noradrenaline – which have many effects, including increasing your heart rate and breathing rate, and making you more alert. Adrenaline can also affect the muscles, speeding up the rate at which they twitch and relax. Together, these effects can help you to confront a problem, or flee if you need to, but in the process, the fight or flight response can make you feel hot, breathless, sweaty, and shaky. **LM**



Hormones released by the body's 'fight or flight' response can make you shaky



Working dog breeds like spaniels and border collies are more prone to chasing and fetching

Why do dogs play fetch?

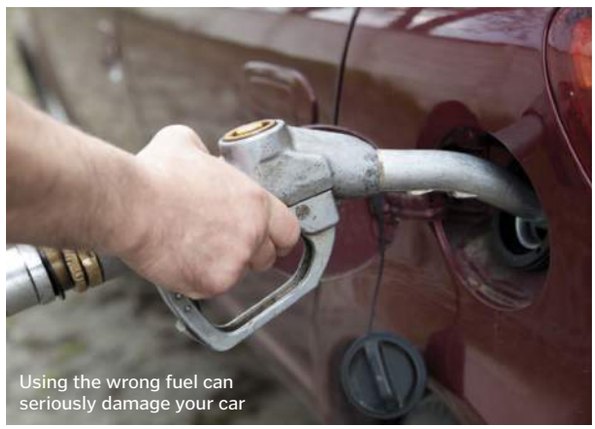
Patrick Brown

The dog's ancestors, wolves, survive by being able to effectively chase down and catch prey. Couple this evolutionary instinct with domesticated dogs being taught to work for us by herding and retrieving things, and it's easy to see how fetching and chasing is a deep-rooted instinct for our canine pals! But as well as following instinct, dogs love to fetch simply because it's great fun. They get to run and play, as well as interact and bond with their owners. When dogs fetch, we give them praise, which makes them want to repeat the action over and over again. **EC**

Why is it bad to put petrol in a diesel car?

Abbi Hennessey

Running a diesel car on petrol can inflict serious damage on the fuel pump, engine and fuel system seals due to the differences in how the two fuels behave. A diesel engine relies on the lubrication provided by additives in the diesel fuel. Without it, the metal surfaces rub together, causing wear on the engine parts and producing fragments of metal. Furthermore, petrol ignites at lower pressure, meaning it is likely to combust too early inside a diesel engine, putting a strain on the mechanics. In case of accidental contamination, experts recommend fully draining and flushing the car. **AC**



Using the wrong fuel can seriously damage your car

BRAIN DUMP

Some species of shark must constantly swim to ventilate their gills, even as they sleep

How do fish sleep?

Bryony Sutcliffe

Many have questioned whether fish do even sleep, because they don't have eyelids and therefore can't close their eyes or experience rapid eye movement (REM). However, scientists have now studied behavioural patterns that suggest fish do sleep, but look more like they are daydreaming. Fish don't lie down, but tend to settle towards the bottom of their watery habitats. Some even need to keep moving while they doze to ensure constant ventilation of their gills. The amount of shuteye a fish gets depends on how active it has been, as well as various environmental factors. Interestingly, they can also suffer from sleep disorders and deprivation. So although fish sleep in a different way to us, there are some similarities. **SB**

FASCINATING FACTS

Why can't pregnant women eat some types of cheese?

Certain soft cheeses should be avoided by pregnant women because they are less acidic than others and contain moisture, therefore providing an ideal environment for harmful bacteria to grow in. **SB**

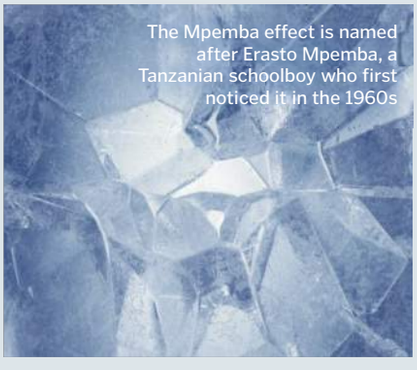
Some soft cheeses can cause illnesses in pregnant women that can harm the foetus

How can hot water freeze faster than cold water?

Eileen Travis

This phenomenon, known as the Mpemba effect, has been such a puzzle that the Royal Society of Chemistry offered a £1,000 reward for an explanation. The full answer is complex (and worth looking up), but the winner, Nikola Bregovic from the University of Zagreb, Croatia, essentially explained that convection currents in the hot water keep it moving, which help it to cool faster by carrying warm water towards the cold edges of the container.

However, Bregovic points out that the freezing temperature of water is not always constant – depending on the conditions, water can become supercooled, and remain liquid below 0 degrees. The temperature that the water eventually freezes at is not always the same, making the results of these experiments slightly different every time. **LM**



The Mpemba effect is named after Erasto Mpemba, a Tanzanian schoolboy who first noticed it in the 1960s

Boomerangs combine the aerodynamics of a helicopter blade, a gyroscope and a frisbee

Why do boomerangs come back?

A boomerang is a spinning, L-shaped wing. It flies because the air flowing over the aerofoil shape of the wing generates lift. But the trailing arm of the L is flying through the disturbed air in the wake of the leading arm, so it gets less lift. This creates a twisting force that tries to bank the boomerang over to the side. Since it is also spinning, the boomerang acts like a gyroscope, which makes it fight the twisting force and travel in an arc instead. Right-handed boomerangs arc around anticlockwise as they fly back to the thrower. **LV**

One Bitcoin is currently worth about £220 ($330)

What are Bitcoins?

Kelvin Li

They are a sort of digital IOU note. Suppose you need to pay me £100 ($150) but Uncle Bob already owes you £500 ($760). You take the IOU from Bob and write down that you owe £100 of that to me, at the bottom. You sign it and give me a copy as proof. I now have an IOU note that allows me to spend up to £100 and you have £400 ($610) of your original debt from Bob left. Bitcoins work like this except that the IOU notes are electronic and use encryption to guarantee the signatures and prevent tampering. The IOU notes are called the 'block chain' and they are distributed around the internet continuously, for anyone to see. This means that Bitcoins don't need a bank to vouch that the money is 'really there'. Bitcoins can be exchanged like any ordinary currency, but they don't have any physical form as cash. **LV**

Stars only twinkle when observed through Earth's atmosphere, which bends their light

Why do stars twinkle?

Lee Cullen

Stars don't actually twinkle: our planet's atmosphere distorts their light, giving the appearance of twinkling when we observe them from the Earth's surface. Differences in temperature, density and turbulence in the atmosphere refract starlight as it passes through. This causes us to perceive fluctuations in the brightness and position of stars, producing their characteristic sparkle, also known as 'atmospheric scintillation'. Stars are so far away that their light seems to come from a single point in space. Since planets are much closer, they occupy a larger area, and changes in their light tend to cancel each other out, making them appear more stable. **AC**

Why can't chickens fly?

Romesh Shira

Chickens *can* fly! They're just not very good at it. Domestic chickens still have the ability to use their wings in order to avoid predators and roost high up in trees. However their body weight is too heavy for prolonged flight. Chickens have been selectively bred to be ground-based birds. Their beaks have evolved to peck food from the floor, and their feet have evolved to walk and scratch rather than perch. Although their wings can provide enough thrust to lift them over a fence, the heavy, dumpy body of a hen just hasn't evolved to let them soar! **EC**

Chickens' flight feathers are often clipped to prevent flying escapes over fences

The appendix is found on the lower right hand side of the body, connected to the large intestine

What causes appendicitis?

Landon Marx

Appendicitis is inflammation in the appendix, which is a small pouch that sits just off the lower right hand turn of your large intestine. In humans, the appendix is small and is not thought to have any important function. However, if it becomes inflamed it can be life threatening.

The exact cause of appendicitis is not known, but according to the NHS, most cases are thought to be triggered by a blockage. A lump of digested food or a swelling in the wall of the gut cuts off the entrance to the appendix, leading to painful inflammation or even a rupture. **LM**

New Brain Dump is here!

Don't miss issue 31 of **Brain Dump**, the digital sister magazine to **How It Works**, when it lands on the virtual newsstand on 3 December. This month, we explain how tequila is made, what will happen when the Sun dies and how truth serum works. You'll also discover why dogs love to lick people and why cats always seem to land on their feet, plus loads more! Every edition is packed with stunning images and fun facts to entertain your friends and family with. Download the new issue of **Brain Dump** at the beginning of every month from iTunes or Google Play. If you have a burning question, you can ask at **www.facebook.com/BraindumpMag** or Twitter – the handle is **@BrainDumpMag**.

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1 Keyless lock technology

August Smart Lock
From $199 (approx £130)
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Leave your keys in your pocket – this system allows you to unlock your home with your smartphone. The companion app connects your phone to the lock via Bluetooth, so that you can open the door by simply tapping your phone screen. It's compatible with iOS and Android, and uses a similar security encryption to that used for online banking. The system is compatible with any door, and will automatically lock when you (and your smartphone) leave the house. If your phone runs out of battery you won't be locked out – your traditional door key will still work.

2 Wireless lighting

Philips Hue Go
£79.99 / $99.95
www.philips-shop.co.uk
Philips has been pushing the boundaries of lighting for a while, and their Hue Go system is no different. This fully portable, wireless lamp lets you experience the type of lighting you want, wherever you want it, moving around your home and the great outdoors. It provides the light that suits the moment, acting as a centrepiece on a table or providing mood lighting for a party, with a full charge lasting around three hours. When you use the Philips Hue app, there are 16 million shades to choose from, providing the perfect lighting for any mood or occasion.

Easy to use
The Hue Go can be operated by your smartphone, but also has a control button on the product itself.

Extra functions
Using light notifications, the Hue Go can alert you to an incoming email or a new weather forecast when connected to your smartphone.

3 Money-saving heating

Nest Learning Thermostat
£249 / $249
www.nest.com
As much as 60 per cent of the average home's energy bill will be heating costs. With Nest's latest gadget, you can precisely control your home's temperature and create a custom heating schedule, which helps prevent energy from being wasted. Just ten to 12 days after installation, the system recognises your heating patterns and will draw up a personalised schedule for you, helping you wake up to the right temperature and save energy while you're away. The Nest app also shows just how much energy you're saving, and will email you with a monthly report that includes tips to help you save even more.

4 Water leak detection

WallyHome
$299 (approx £194)
www.amazon.com
The Wally uses a wireless sensor network and the existing wiring in your home to detect water leaks and changes in humidity and temperature. Wally is constantly connected to all of its sensors and your smartphone, sending immediate alerts when an issue is detected. If you want, you can even set up Wally's concierge service to immediately call an engineer to come and look at a particular problem. Wally also benefits from ultra-low power technology, helping its original battery last for over ten years.

EXTRAS

Smarten up your home with these handy resources

BOOK

Smart Homes For Aging Adults

£8.99 / $15
www.amazon.co.uk
As the world's population continues to age, the need for more helpful home technology is growing. This e-book explains 13 tech solutions and services that will support the elderly in their own homes, enabling them to live independently for longer.

APP

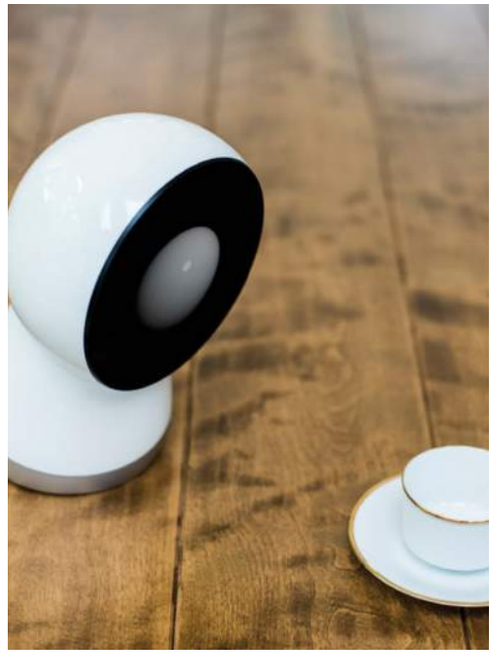
Control4 MyHome

Free
iTunes, Google Play
Control4 MyHome helps you control your energy consumption, entertainment and lighting systems via your smartphone. It does require you to take out a subscription to 4Sight in order to have a completely secure 3G/4G connection, though.

WEBSITE

ADT Pulse

Free
iTunes, Google Play
This clever app helps you manage and protect your home while you're away, allowing you to remotely control your alarm. It will send you a text or email when it detects a problem, such as a water leak, and can also be used to control your heating and lighting.



5 Robot helper

Jibo
$749 (approx £490)
www.jibo.com
Dubbed by its creators as the world's first family robot, Jibo is equipped with a range of functions to make day-to-day life that little bit easier. Its two high-resolution cameras track faces and can even capture photos when you smile, while 360-degree microphones enable you to talk to Jibo wherever you're stood in the room. Like a personal assistant, the robot can deliver hands-free reminders and can recognise each member of your family in order to pass on the right messages to the right people.

6 Smart sensor system

Sen.se Mother
£245 / $299
sen.se/mother
The Sen.se Mother uses four motion 'cookies' to monitor just about anything in your home, sensing movement, temperature changes and the presence of other objects. It takes only two minutes to prepare the cookies for a new task, making it easy to swap their function as you wish. The 'Mother' unit works as an in-home broadcaster, sending and receiving transmissions to and from the cookies, uploading data to an app that lets you view exactly what the system has recorded. Whether you want to track your coffee consumption or measure how long you brush your teeth for, the Sen.se Mother promises to have you covered.

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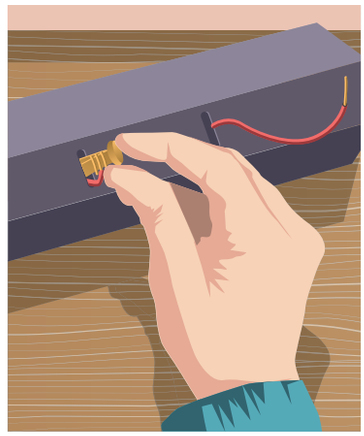
Make a torch

Learn the science behind electrical conduction with a few household items

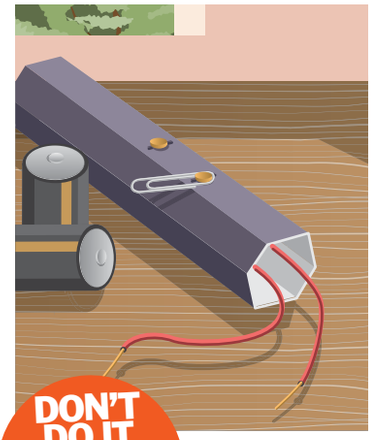
1 Prepare the casing

The main body of your torch will be a 0.5-litre (0.11-gallon) plastic bottle and a cardboard sweet tube. Cut the neck off the bottle at the widest point with some scissors – this will form the end of the torch. Line the inside of the bottle neck with tin foil, fixing it in place with either glue or sticky tape. Next, remove the top from the cardboard sweet tube, which will hold the batteries in place.



2 Add the wire

Carefully cut two vertical slits in your sweet tube, the length of a paper clip apart. Strip both ends of two 15-centimetre (six-inch) pieces of wire using a pair of wire strippers and then thread a piece through each of the slits that you have cut. Then, take a small brass fastener and wrap one of the exposed ends around its centre, then press it through the cardboard slit.



3 Attach your switch

Repeat this step with the remaining wire, but add a paper clip onto the brass fastener before winding the wire round. Inside the tube, bend back the fastener legs to secure them in place, but make sure they don't touch, as this will break the circuit. Tape two 1.5-volt C batteries together with opposite charges touching, then tape one end of the wire to the end of the bottom battery. Push both batteries into the cardboard tube.

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

4 Secure the bulb

It's important to ensure that you fit the batteries tightly, because if they are able to move the connection may break. In that case, the circuit would not be complete and your torch wouldn't light. If your tube is too long, you can pack it with some modelling clay. Next, wrap the last piece of exposed wire around the bottom of your small bulb, and then secure it against the top of the battery with some more clay.

5 Put it all together

To complete your project, take the end of the torch you made in the first step and secure it to the sweet tube with some tape. Then touch the paper clip against the other brass fastener to complete the circuit and allow electricity to flow, turning your torch on. The reflective foil will concentrate the light into a directed beam.

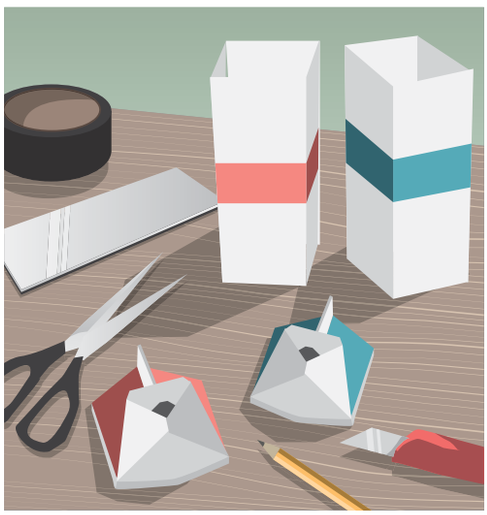
In summary...

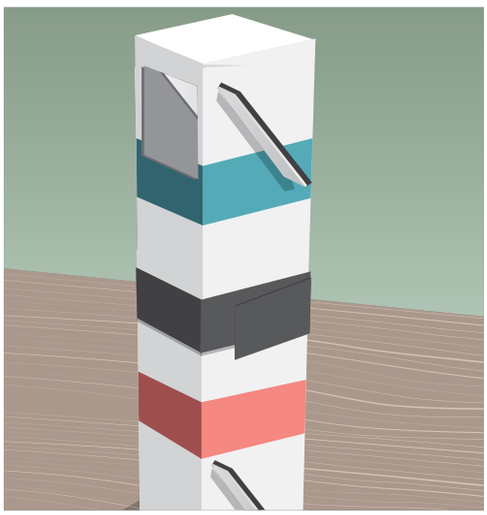
Conductive materials are made of atoms with free-moving electrons; when they are connected to a source of electricity, the negatively charged electrons flow towards the battery's positive end, initiating a current. The current flows through the circuit so it reaches the bulb and heats the filament, producing light.

NEXT ISSUE
- Build a spectroscope
- Make a foldable egg

Construct a periscope

Build your own piece of submarine tech to see around corners and over walls





Illustrations by Edward Crooks

1 Assemble your cartons
Cut the tops off two standard milk or orange juice cartons, and rinse them well. Leave them to dry and then tape both of the open ends together, forming one long, narrow box. Using a pair of scissors, cut a square out from the side of the box at one end, and then repeat this on the corner diagonally opposite. These holes will let light into the periscope, which will be reflected by mirrors and enable you to see out the other side.

2 Cut your slots
Lay your box on its side, and use a protractor to mark an angle of 45 degrees at each end. It's vital that these lines both slope away from the squares you cut, because otherwise the mirrors will be facing the wrong way. Draw lines at this angle on each side, making sure that they match the length of your mirrors. Turn over the box and repeat. Gently cut along these lines with scissors, making sure you don't widen the gap too much.

3 Insert your mirrors
Carefully slide your mirrors into the slots you've cut, making sure they fit securely and that the shiny sides face each other. Push them all the way in until they reach the other side of the carton. Your periscope is now ready to see around corners and over walls; all you need to do is look at the bottom mirror and point the top one in the desired direction! For the ultimate periscope, you can disguise it with some camouflaged paint or stick on leaves and foliage.

In summary...

We see objects when light – from the Sun or a lamp, for example – reflects off them and into our eyes. Light only travels in straight lines, but the mirrors inside the periscope are able to change its route. The top mirror reflects the light towards the bottom mirror where it is reflected again and enters the eyes, allowing the object to be seen.

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Letter of the Month

The planet on its side

Dear **HIW,**
I love your magazine and read it every month. It is definitely the best magazine on the market! I was wondering why the planet Uranus is tilted on its side?
Thanks,
Henry Jalland (aged 13)

Thanks for your question and kind words, Henry. Uranus actually has the largest tilt of any planet in our Solar System, spinning more or less on its side. A 2011 study suggested that the giant planet was thrown on to its side by multiple collisions in the early days of the Solar System rather than a single impact, as was previously believed. The result is a huge 98-degree tilt, far greater than any other planet in our Solar System (Earth's tilt is only 23.5 degrees while Neptune and Saturn both tilt at 29 degrees). This has made Uranus somewhat of an oddball, as its north and south poles lie where most planets have their equator.

The multiple impact theory helps to explain why Uranus's moons orbit as they do today. A single impact would have left them displaying retrograde motion; in other words, they would be orbiting in the opposite direction to Uranus' spin. Simulations show the most likely scenario was a double impact while Uranus's moons were still forming.

Like the other giant gas planets, Uranus has no solid surface

Does music help you sleep?

Dear **HIW,**
When I go to bed, I always wonder if there's anything that can help me get to sleep. I've tried listening to music, but does this actually help?
Thanks,
Daniel Cameron (aged 11)

It depends on the person, and the way in which they normally go to sleep. Several studies have found that slow music, between 60 and 80 beats per minute, helps some people to become more relaxed and gradually fall asleep. However, it may take time to adapt to this process, particularly if you have never used music in this way. It's key to listen to something you don't have an emotional attachment to, as this tends to stimulate a reaction in your brain, keeping you awake for longer.

Music can mask disruptive, ambient noise, allowing you to drift off nice and quickly

Why do clouds form in different shapes and sizes?

Dear **HIW,**
Clouds are all made up of tiny drops of water, so why do they form in different shapes and sizes?
Thanks,
Ewan Alexander

Clouds form when the air becomes saturated with water vapour, which means that it cannot hold any more moisture. This happens either when the amount of water in the air has increased through evaporation, or when the air has been cooled to its dew point and condensation has occurred. There are a number of variables that can alter the way a cloud forms, including the height and the prevailing air currents. Scientists recently discovered that the cloud-forming particles in the atmosphere, known as aerosols, have an important role in determining the shape, size and type of cloud that forms.

The water droplets in clouds are incredibly small; one cubic metre (35.3 cubic feet) of air will contain roughly 100 million droplets

Grief causes a surprising number of physical changes in our body; it is much more than just a state of mind

The science of grief

Dear **HIW,**
I always love reading your magazine and find out lots of great information on areas I've always wondered about. My question is, what happens inside someone's brain when they experience grief and is there anything anyone can do to help?
Thank you,
Amy Lippiatt

When we are unfortunate enough to lose someone we love, an ancient reaction in our brain is triggered that's commonly called 'fight-or-flight'. This is often activated by danger or fear, but it is believed we also evolved to use it when grieving because our bonds with others were so important to us; they were often the key to survival as we relied on others to hunt or avoid danger in groups. We become tense as our brain has stimulated us to take action, but there is nothing we can do to resolve the situation. The production of corticotropin-releasing hormone increases, causing us to feel anxious, and possibly disturbing our biological rhythms. Our digestion, circulation, metabolism and respiration may all be altered by grief. There is no simple fix, but it is advisable to visit a doctor for a physical check up.

"Our bonds with others were the key to survival"

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Just read my son's **@HowItWorksmag** and what a super publication it is. I'm hooked!

@xxRachxx
@HowItWorksmag my 2 absolutely love finding out how things are made and how they work!

@neiltyson
Kudos to **@NASANewHorizons** for taking us from a fuzzy blip to a face-on close up of Pluto's moon Charon

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In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual – Galileo Galilei

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Germany paid their last reparations payment for World War I on October 3, 2010

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The Martian is the best advert for a career in engineering I've ever seen.

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Cover images
Alamy, Rex Features, Startpoint 2015, Thinkstock, Tobias Roetsch

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Email: howitworks@servicehelpline.co.uk
13 issue subscription (UK) – £43.50
13 issue subscription (Europe) – £53
13 issue subscription (USA) – £53
13 issue subscription (ROW) – £64

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Printing & Distribution
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Distributed in the UK, Eire & the Rest of the World by: Marketforce, Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU
☎ 0203 787 9060
www.marketforce.co.uk

Distributed in Australia by: Network Services (a division of Bauer Media Group), Level 21 Civic Tower, 66-68 Goulburn Street, Sydney, New South Wales 2086, Australia
☎ + 61 2 8667 5288

ISSN 2041-7322

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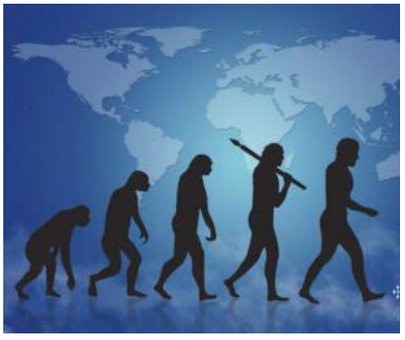

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The Desert Rats' Cromwell

A vehicle made famous by the British 7th Armoured Division, who had been dubbed the Desert Rats for their exploits in North Africa. However, the 7th Armoured were not issued with Cromwells until 1944, when they returned to the U.K. to prepare for D-Day. They fought in their Cromwells across France and into Germany, and eventually took part in the Victory Parade on September 7, 1945, in Berlin.

Development for the Cromwell first began in 1940 when the General Staff knew the Crusader would soon become obsolete. The tank was the fastest British tank to serve in the war, with a top speed of 40 mph (64 km/h). Its dual purpose 75 mm main gun had HE and armour-piercing capabilities and its armour ranged from 8 mm up to 76 mm overall.

In World of Tanks, you can command the Cromwell from the driver's seat. World of Tanks is an online PC game dedicated to tank warfare in the mid-20th century, with over 300 of history's most iconic tanks.
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